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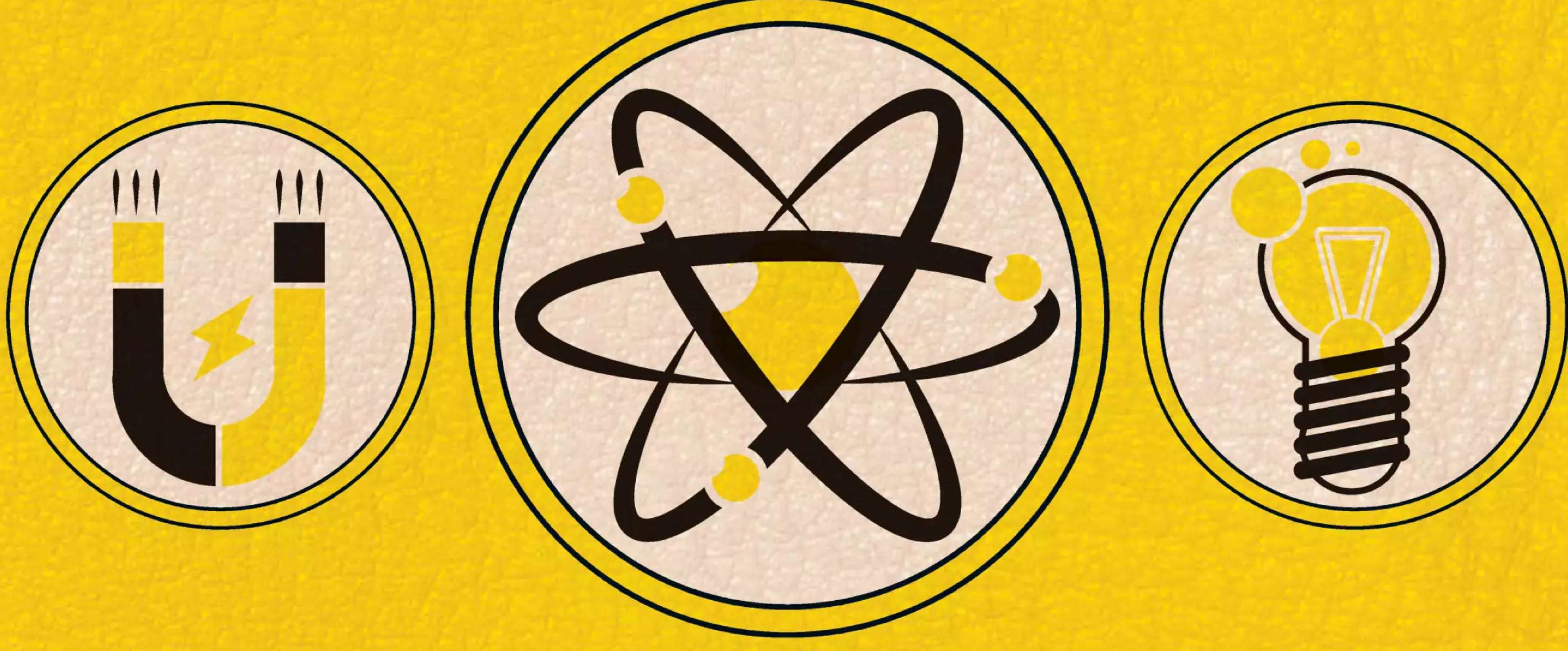
HOW IT WORKS

AMAZING PHYSICS

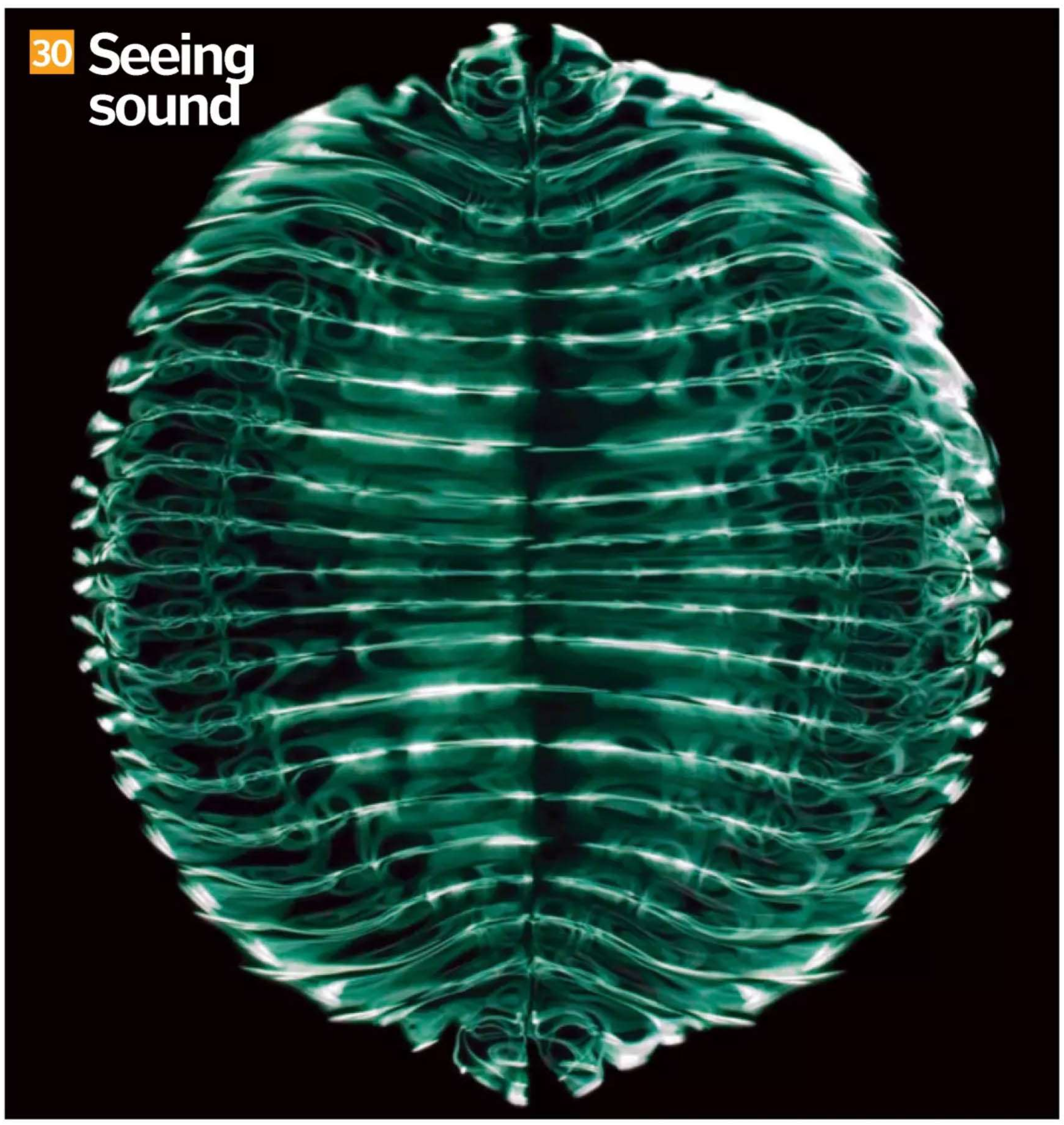


CONTENTS

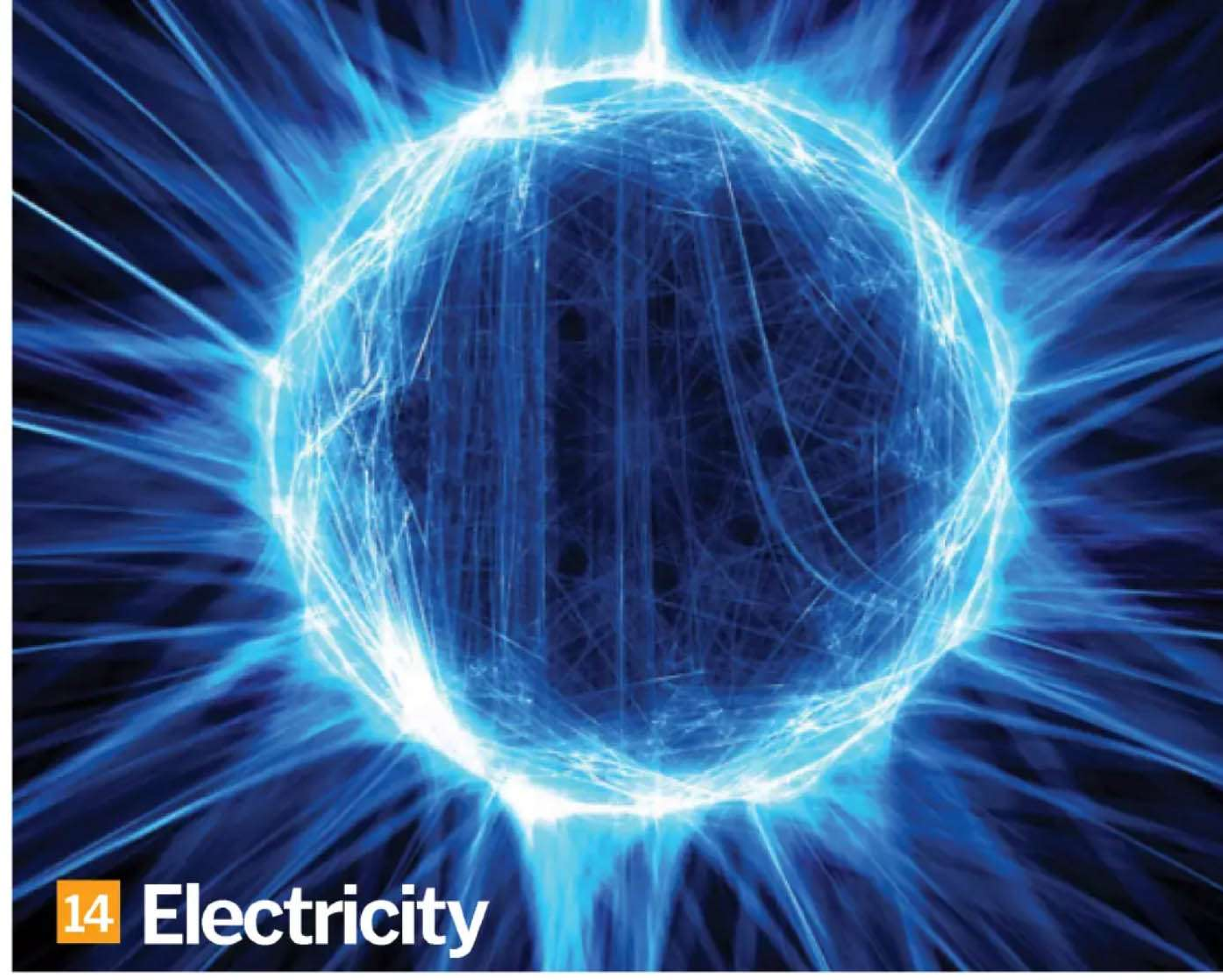
4 FORCES EXPLAINED

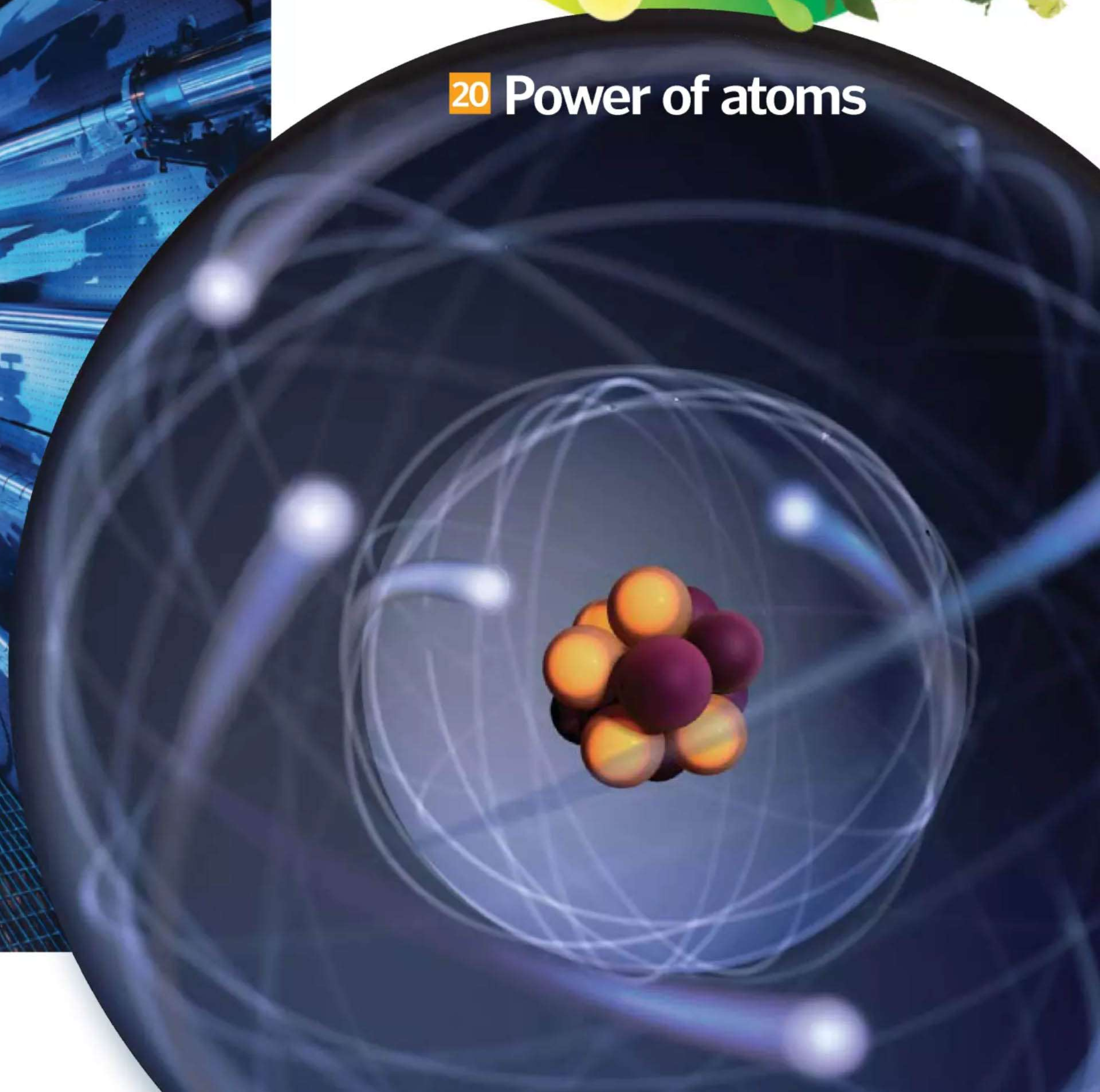
Understand the invisible powers that govern everything we do

12 Gases



30 Seeing sound





FORCES EXPLAINED

Understand the invisible powers that govern everything we do

Isaac Newton was the first to point out that without forces, objects would not move – thereby describing the concept of inertia. From the smallest atoms to the largest stars, everything is governed by four fundamental forces: gravitational force, electromagnetic force, nuclear weak force and nuclear strong force. If any one of these were taken away, with the possible exception of the weak force, the universe as we know it would be unrecognisable.

Gravity keeps our feet firmly on the floor and tethers the planets into orbits around the stars. Wherever there is matter there is gravity, and without it, the universe as we know it could not exist. Matter would never have condensed to form the first stars after the Big Bang.

The weak force governs nuclear fusion and radioactive decay and is the only force capable of changing the types (or 'flavours') of subatomic particles, which are known as quarks. These particles make up the protons and neutrons that come together to become the nucleus of an atom. There is a hypothetical model of a 'weakless universe', but without the weak force to mediate the fusion reactions that power the stars, it is not known if the model would work.

The electromagnetic force is responsible for the sticking force of friction, and is the reason that solid objects don't move through one another when they collide. It creates the pull of a magnet, and is responsible for the upward force of buoyancy in water. Most importantly, though, the electromagnetic force holds negatively charged electrons in orbital shells around the nucleus of every atom and allows those atoms to come together to form molecules. The nucleus itself is held together by the nuclear strong force, so if one of these forces were missing, atoms could not exist and neither could the universe that we live in.

Fundamental forces of physics

Uncovering the four forces that rule the entire universe

5 TOP FACTS
MAGNET TRIVIA

Magnetic elements
1 Iron, nickel and cobalt are the only three magnetic elements. Some of the others, like oxygen, react to magnetic fields, but the interaction is barely detectable.

Hot magnets will break
2 Magnets are made by applying an electrical current to metal, forcing the magnetic domains to align. Heating the magnet allows the domains to fall out of alignment.

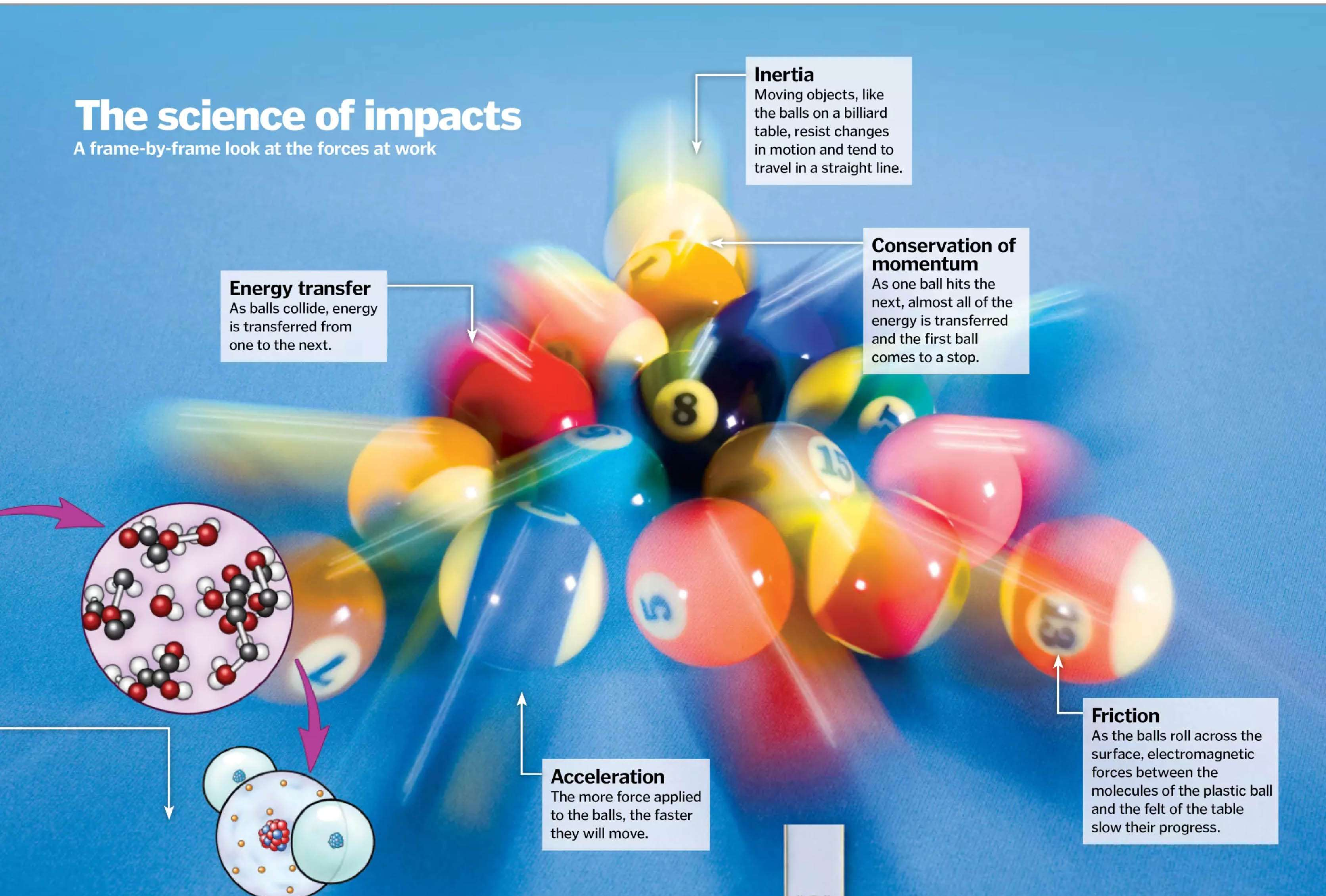
Shark repellant
3 Sharks sense electromagnetic fields in the water and use this ability to locate their prey, but faced with a strong magnet, their senses are overwhelmed and they back away.

Levitating trains
4 Strong magnets keep maglev trains levitating a few millimetres above the track, minimising friction. They can also provide thrust that drives the trains forward.

Weak magnetic field
5 Earth's magnetic field at the surface is around 100 times weaker than a fridge magnet. Despite this, it's still strong enough to protect Earth from solar wind.

DID YOU KNOW? *Some physicists believe gravity is transmitted by hypothetical particles known as gravitons*

The science of impacts
A frame-by-frame look at the forces at work



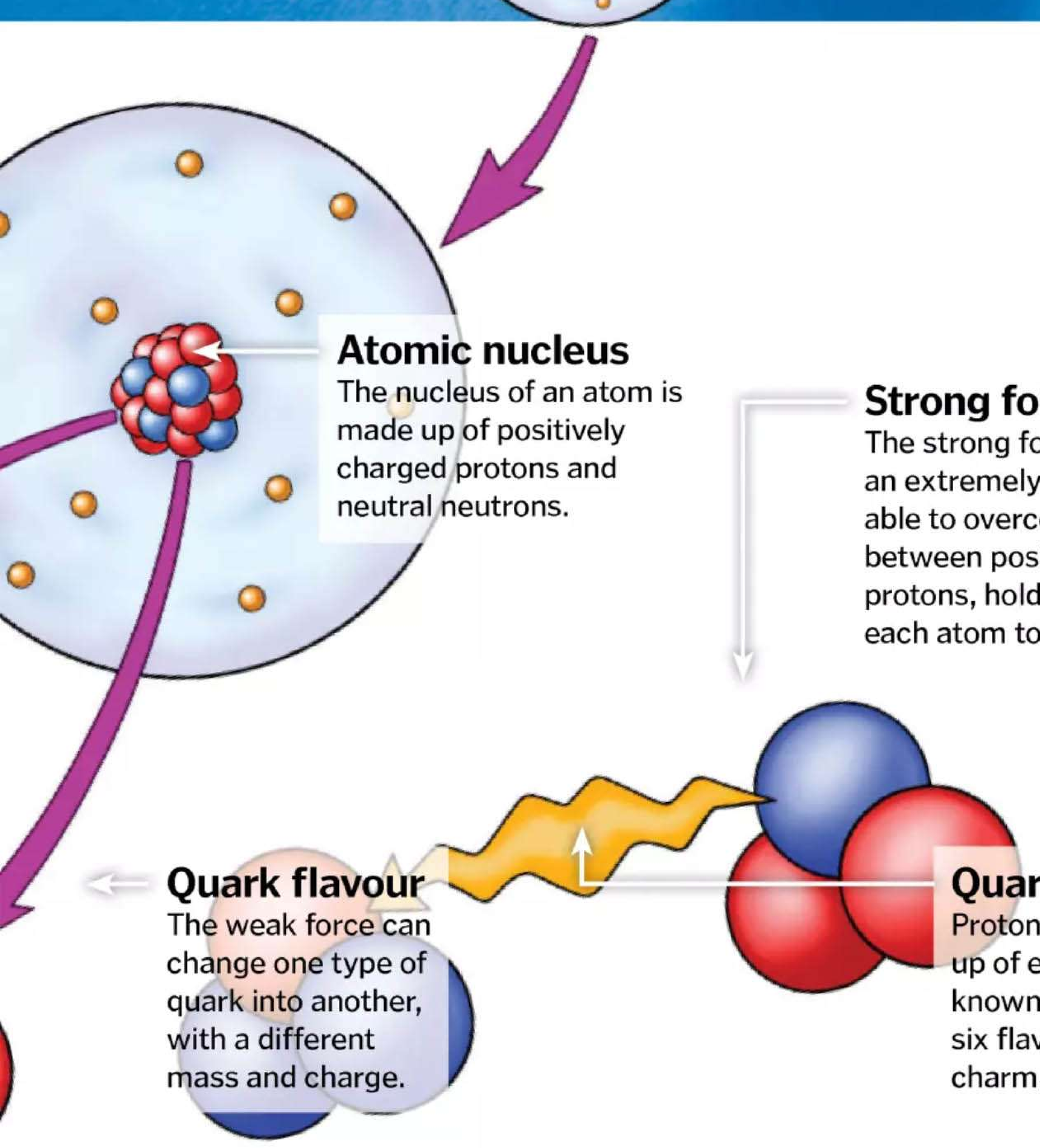
Inertia
Moving objects, like the balls on a billiard table, resist changes in motion and tend to travel in a straight line.

Conservation of momentum
As one ball hits the next, almost all of the energy is transferred and the first ball comes to a stop.

Energy transfer
As balls collide, energy is transferred from one to the next.

Acceleration
The more force applied to the balls, the faster they will move.

Friction
As the balls roll across the surface, electromagnetic forces between the molecules of the plastic ball and the felt of the table slow their progress.



Atomic nucleus
The nucleus of an atom is made up of positively charged protons and neutral neutrons.

Strong force
The strong force only acts over an extremely short range, but is able to overcome the repulsion between positively charged protons, holding the nucleus of each atom together.

Quark flavour
The weak force can change one type of quark into another, with a different mass and charge.

Quark
Protons and neutrons are made up of elementary particles known as quarks. They come in six flavours – up, down, strange, charm, bottom and top.

How to measure the invisible

Forces cannot be seen, but the effects they have on matter can be used to measure them. When a spring is stretched by a force, it lengthens in proportion to the force applied: if there is twice as much force, the spring will lengthen twice as much. By measuring the length of the spring, the relative magnitude of the force can be determined.

Force is measured in comparison to a standard benchmark; one newton (N) is equal to the amount of force required to accelerate a mass of one kilogram by one metre (2.2lb by 3.3ft) per second every second. For example: on Earth, for every 1kg (2.2lbs) of mass, the force of gravity is 9.8 newtons (N), so (ignoring the effect of air resistance), if dropped from the roof of a supermarket, a 1kg bag of sugar would accelerate toward the ground at a rate of 9.8 m/s^2.

> *"Terminal velocity is reached when the downward force of gravity is matched by air resistance"*

How fast can you fall?

As a skydiver drops from a helicopter, they accelerate toward the ground due to the force of gravity. But they do not continue to speed up indefinitely. The molecules in the Earth's atmosphere block their path and as they collide with them, the interaction creates drag. The amount of drag generated is directly related to the speed of the skydiver and as they fall toward the ground, the resistance increases, opposing the downward pull of gravity, in turn slowing their acceleration.

Terminal velocity is reached when the downward force is matched by air resistance: at this point, the skydiver cannot fall any faster. It is a myth that everyone falls at the same speed. Terminal velocity is not a constant and is affected not only by the weight of the skydiver, but also by their body position. In a face-down freefall position, the average terminal velocity is 193 kilometres (120 miles) per hour, but head first, a skydiver can exceed 322 kilometres (200 miles) per hour.

KEY DATES
THE DISCOVERY OF FORCES

1452-1519
Leonardo da Vinci studies friction and makes hundreds of observations in his journals.

1564-1642
Galileo notes that moving objects are affected by friction and that heavy objects don't accelerate faster than light ones.

1687
Isaac Newton publishes his three laws of motion, laying the foundations for classical mechanics.

1831
Michael Faraday discovers that electricity can induce a magnetic field in an iron ring.

1932
James Chadwick discovers the neutron, leading to the discovery of the nuclear strong and weak forces.

DID YOU KNOW? *The strongest naturally occurring magnet is lodestone. It is just strong enough to lift a paperclip*

Why do we sink?

When a diver drops into the sea, their body fills the space once occupied by water molecules, so an equal volume of water must move out of the way to make room – a phenomenon known as displacement. The water exerts pressure on the diver, pushing upward with a force equal to its weight.

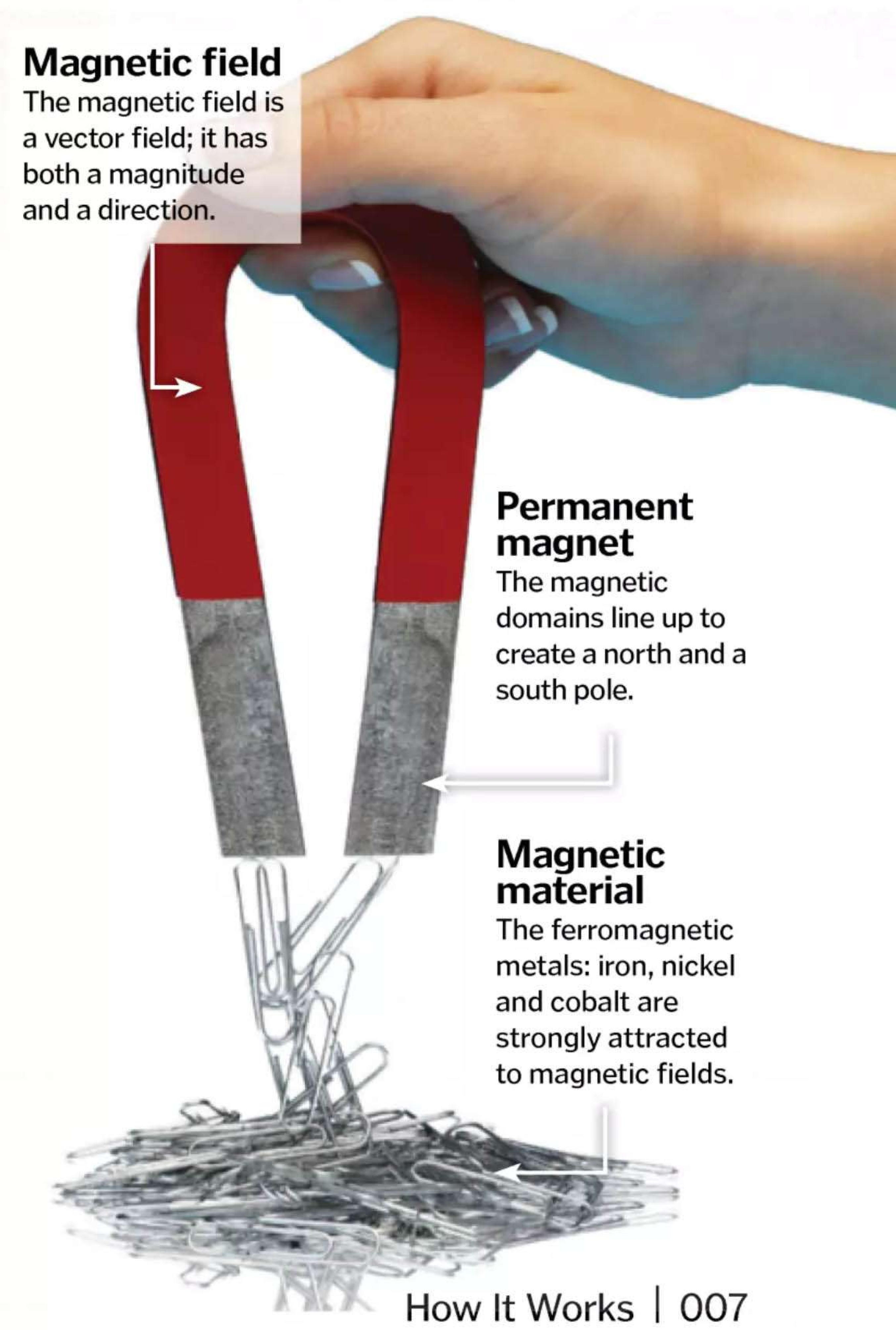
Objects of the same volume displace the same amount of water, therefore experiencing the same buoyant force. Why then, does a basketball float, while a bowling ball sinks? This is down to density. The bowling ball has more matter crammed in to the same volume, so the pull of gravity, or its weight, is higher. When the weight of an object is greater than the weight of the water it displaces, the object sinks.

Magnetism

Magnetic fields are generated by attraction and repulsion between electrons. The electrons around the nucleus of an atom are not only negatively charged; they also act like miniature magnets. According to quantum mechanics, each electron has a 'spin', creating a tiny magnetic dipole.

In nonmagnetic materials, most of the electrons are arranged so that their magnetic moments cancel each other out, but in ferromagnetic metals like iron, there are unpaired electrons in the outer orbitals. On their own, the forces are small, but when aligned with billions of others, the cumulative magnetic field can be felt.

The fields generated by adjacent atoms of magnetic metals naturally come together to form miniature magnetic domains. In natural magnetic materials, these domains are randomly orientated, but if an electrical current or a magnetic field is applied, they can be forced into alignment, creating a magnet.



"Elastic materials, like steel and bungee rope, deform under tension and compression"

What makes materials stretch?

Stress inside a material can be caused by a number of forces, like gravity, friction or pressure. There are two types: tension and compression. Elastic materials, like steel and bungee rope, deform under tension and compression, altering their shape to accommodate the force, and recoiling again when it is removed. In contrast, brittle materials like concrete are only elastic over a small range and rapidly reach their breaking point when stress is applied.

RECORD BREAKERS
BIGGEST LEAP

400ft

HIGHEST BUNGEE JUMP

72-year-old Ray Woodcock holds the record for the highest-ever bungee jump into water after plunging a terrifying 121.92m (400ft).

DID YOU KNOW? One of the most common injuries from bungee jumping is damage to eyes due to the increase in pressure

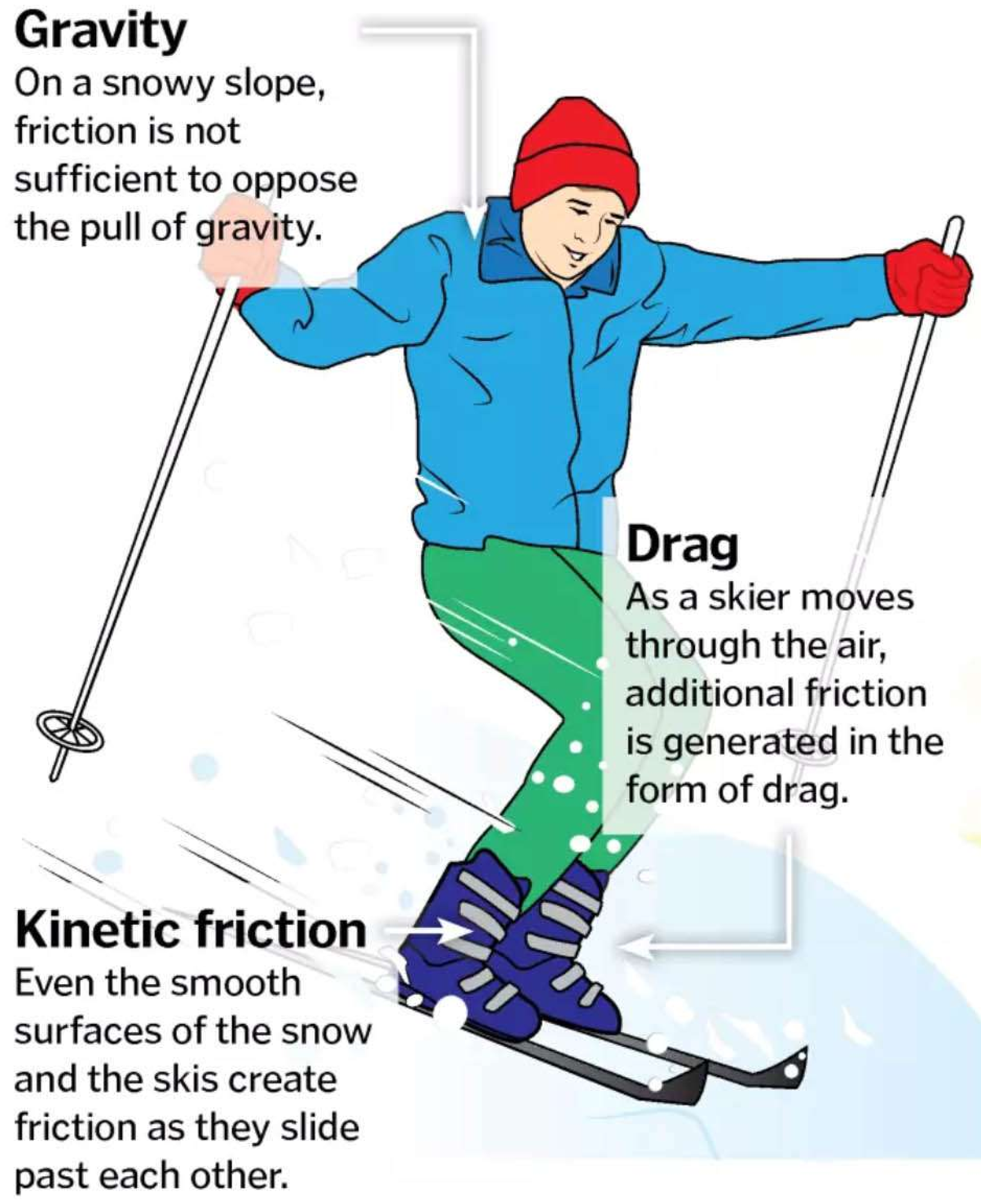
Bouncing back

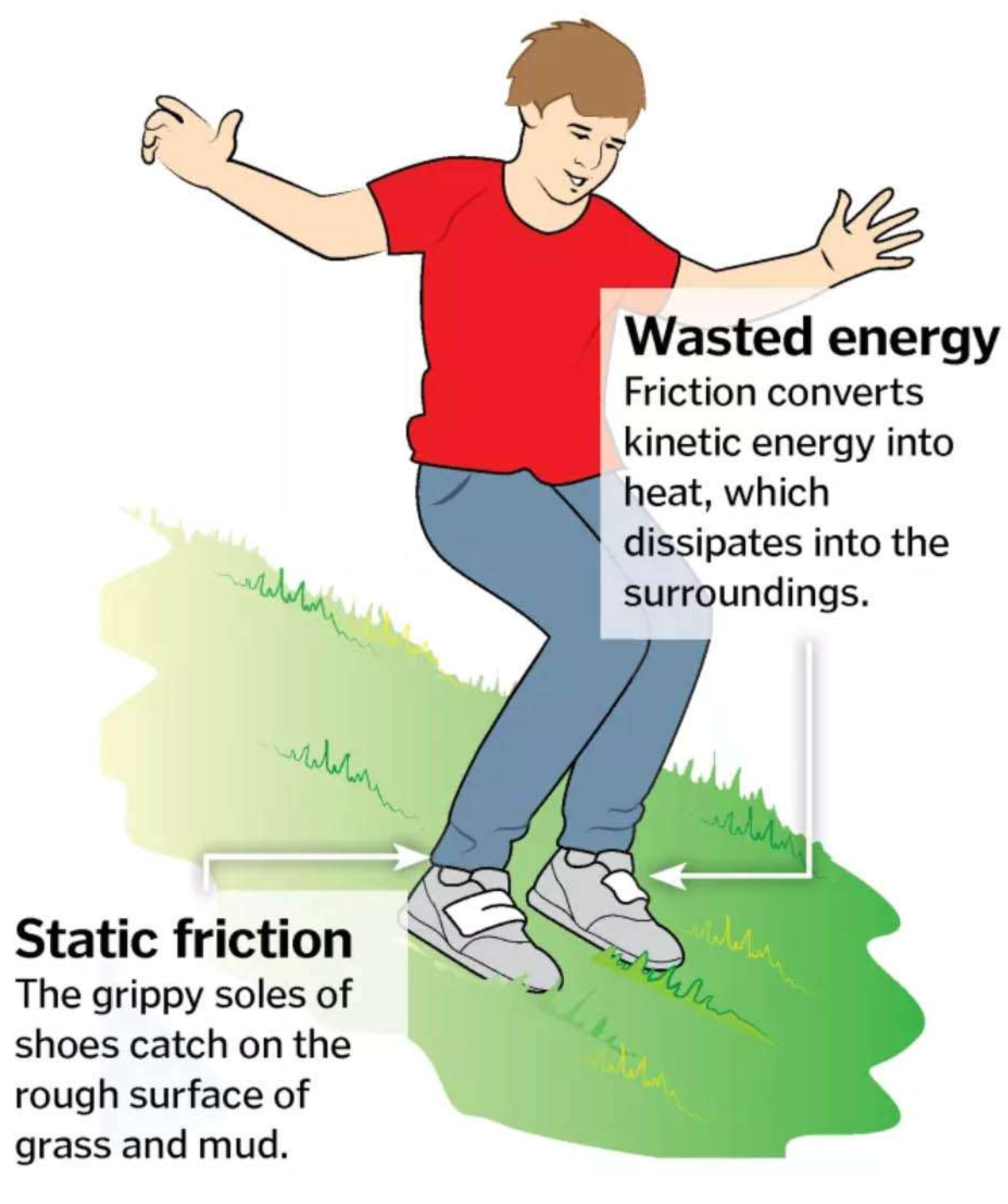
The stress of a bungee jumper pulling on a bungee rope causes it to stretch and deform, but it does not snap. The force is resisted by strain. The forces generated during a bungee jump are within the elastic limit of bungee cord and strain increases proportionally to stress. When the force is removed, the length of the rope returns to normal. Beyond the elastic limit, in the plastic region, the cord can stretch further, but will not fully bounce back, and at very high stress forces, it will reach breaking point and snap.

What creates and controls friction?

Friction is the force that resists the movement of one object relative to another. It can be static where neither object is moving – or kinetic – when one or both of the objects are in motion. Friction is the result of a combination of factors. Rough surfaces, like sandpaper, catch and drag as they move past one another because of irregularities in their surface, but, some of the most highly polished surfaces, like glass, create lots of friction too.

A mirror might look smooth, but touch it and your finger will cling. Slide your hand over rough-ground glass and it will move much more easily. This is thought to be down to a fundamental force – electromagnetism. As two objects move relative to one another, interactions between electrical charges in the molecules cause the surfaces to stick together. Individually, these interactions are weak, but across a large contact area, like a smooth pane of glass, they quickly add up.





> "To explain the physics of what happens if you jump in a lift, fake forces must be used"

Fake forces

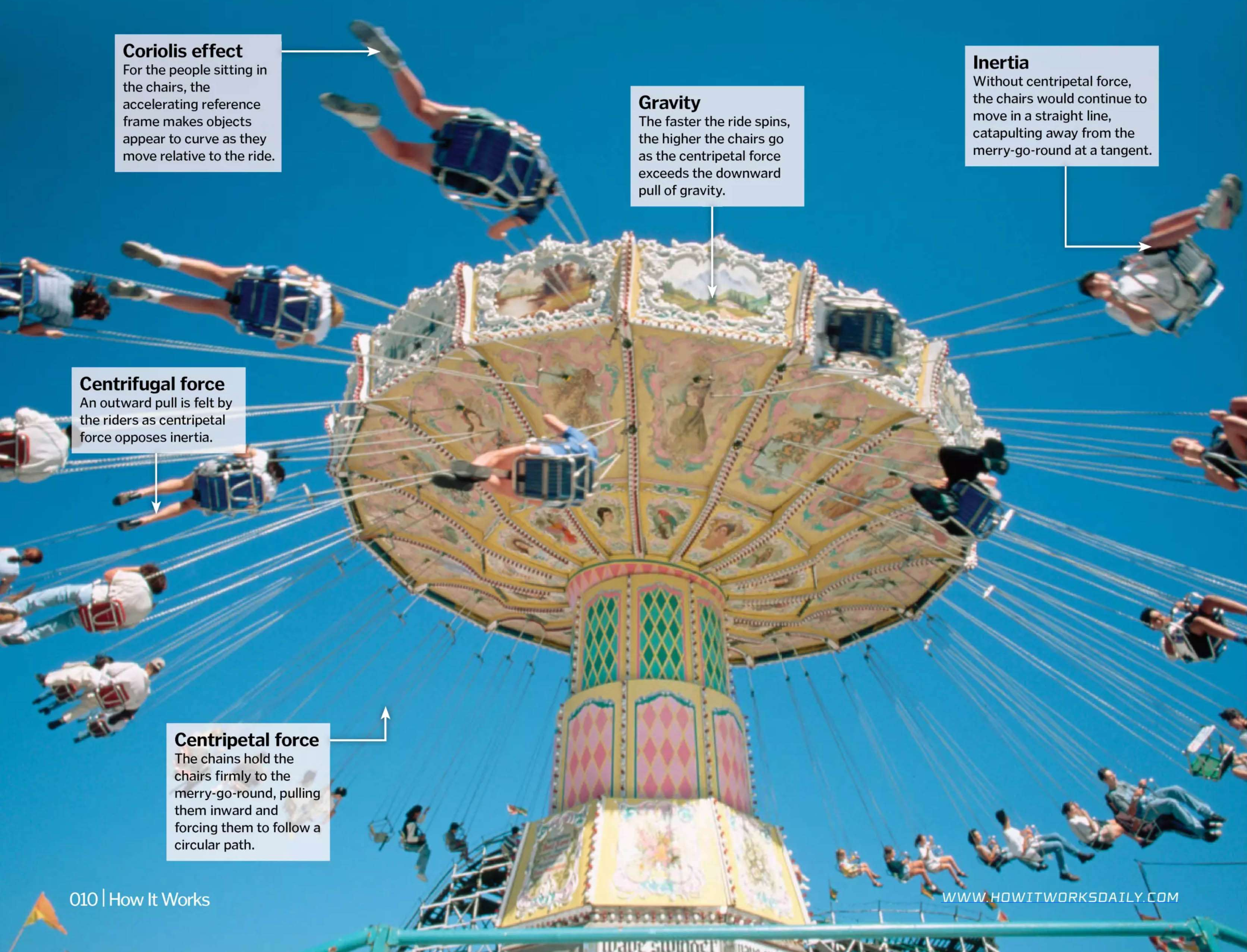
Newtonian mechanics work fine when we are standing still, but what happens when the reference frame is moving? To explain the physics of what happens if you jump in a lift as it travels between the floors of a building, or what happens if you throw a ball while spinning on a merry-go-round, fake forces must be used.

If a rider on a merry-go-round throws a ball to a person waiting on the ground, to any onlookers, the ball follows Newtonian physics and travels in a straight line toward the catcher, dropping in an arc as it is pulled down by gravity. But to the person who threw the ball, it appears to curve away. The ball does not actually curve, but because the thrower is accelerating, the ball looks like it is changing direction. This is known as the Coriolis effect.

Spinning around

From the ground, it is clear how a merry-go-round works; the chains pull the chairs inward, forcing them to travel in a circle. But from the perspective of the riders, an additional force seems to be at play; as the chairs spin round, it feels like something is pulling them outward.

According to the law of inertia, the accelerating riders should travel in a straight line, but the chains attached to the central spindle of the ride prevent forward motion. Instead, the chairs change direction, rotating around the spindle in a circle. As this happens, the bodies of the riders continue to try to move in a straight line, and the pulling feeling as the chairs twist them around is centrifugal force.



DID YOU KNOW? *The gravity on Mars is 3.71m/s², around a third of the gravity on the surface of Earth*

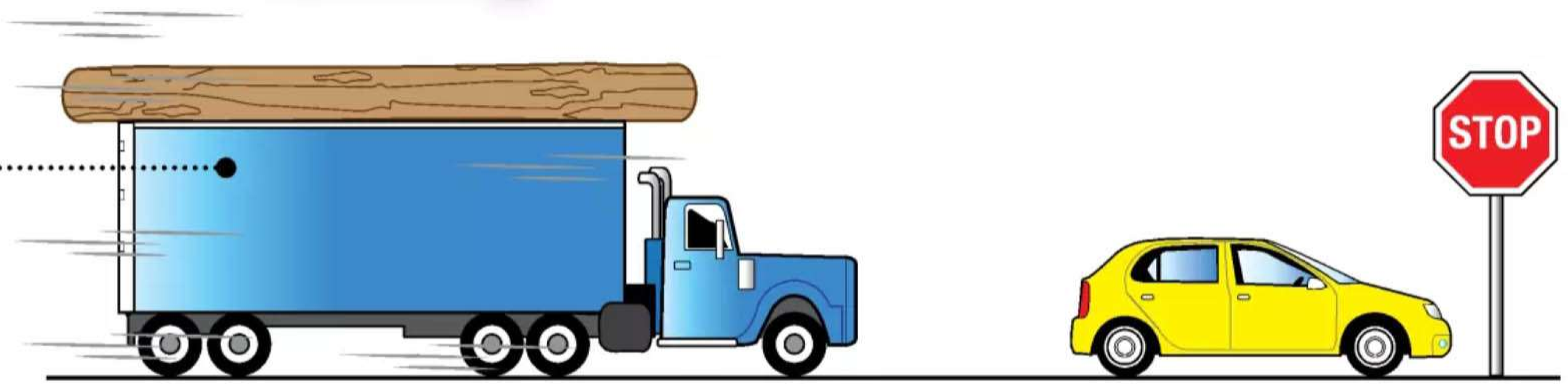
What are the three laws of motion?

Newton's laws of motion explain how things move and interact. The first law essentially describes inertia; the tendency of objects to resist changes in motion. It is the reason a ball doesn't roll along the floor until you kick it and why spacecraft continue to drift through the Solar System even after their fuel is spent. The second law describes how the force required to move an object is related to the mass of the object and explains we can push a bike much faster than we can push a car. The third and final law explains what happens when two objects interact. As your feet push down on the floor, the floor pushes back.

Newton's first law

A body in motion tends to stay in motion

Inertia
Once an object is moving, it will continue to move in a straight line unless a force is applied.

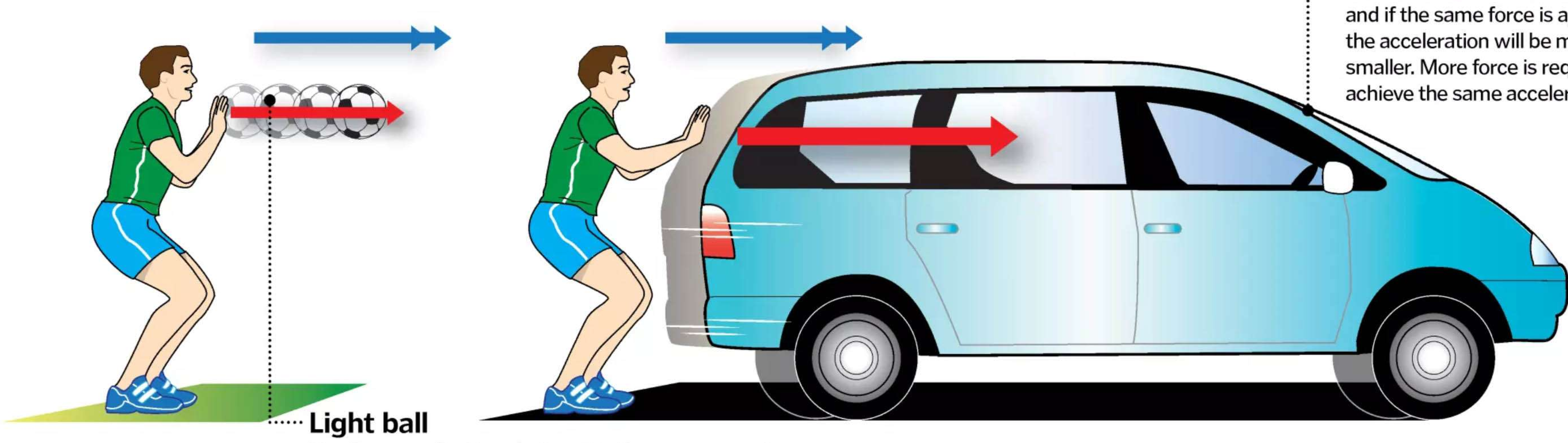


Collision
As the truck strikes the stationary vehicle, the normal force at the point of contact causes it to stop. The log on top of the truck does not hit the car, so it continues to move forward.

Newton's second law

Force is equal to mass times acceleration (F=ma)

Heavy car
The car is heavier than the ball, and if the same force is applied, the acceleration will be much smaller. More force is required to achieve the same acceleration.



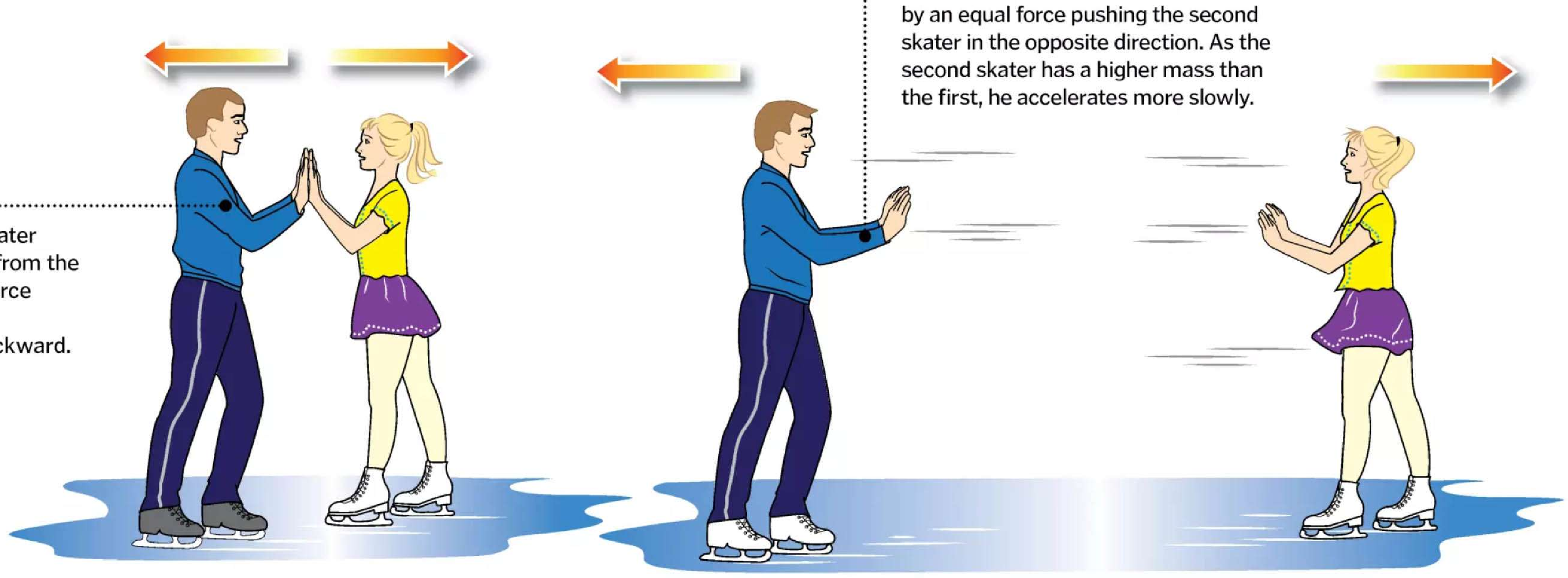
Light ball
The force applied to a ball as it is thrown causes it to accelerate through the air. The acceleration is equal to the force divided by the mass: the ball has a low mass, so it accelerates quickly.

Newton's third law

For every action, there is an equal and opposite reaction

Reaction
The push of the first skater is matched by an equal force pushing the second skater in the opposite direction. As the second skater has a higher mass than the first, he accelerates more slowly.

Action
As the first skater pushes away from the second, the force causes her to accelerate backward.



Heated air is less dense than cool air, hence why hot-air balloons rise

Expansion

Gases typically expand, or increase in volume, when they are heated. Specifically, gas molecules move apart when heated, making the gas as a whole take up more space. All gases expand at the same rate if they are under the same amount of pressure. Gases can also expand without heat if the pressure lowers.

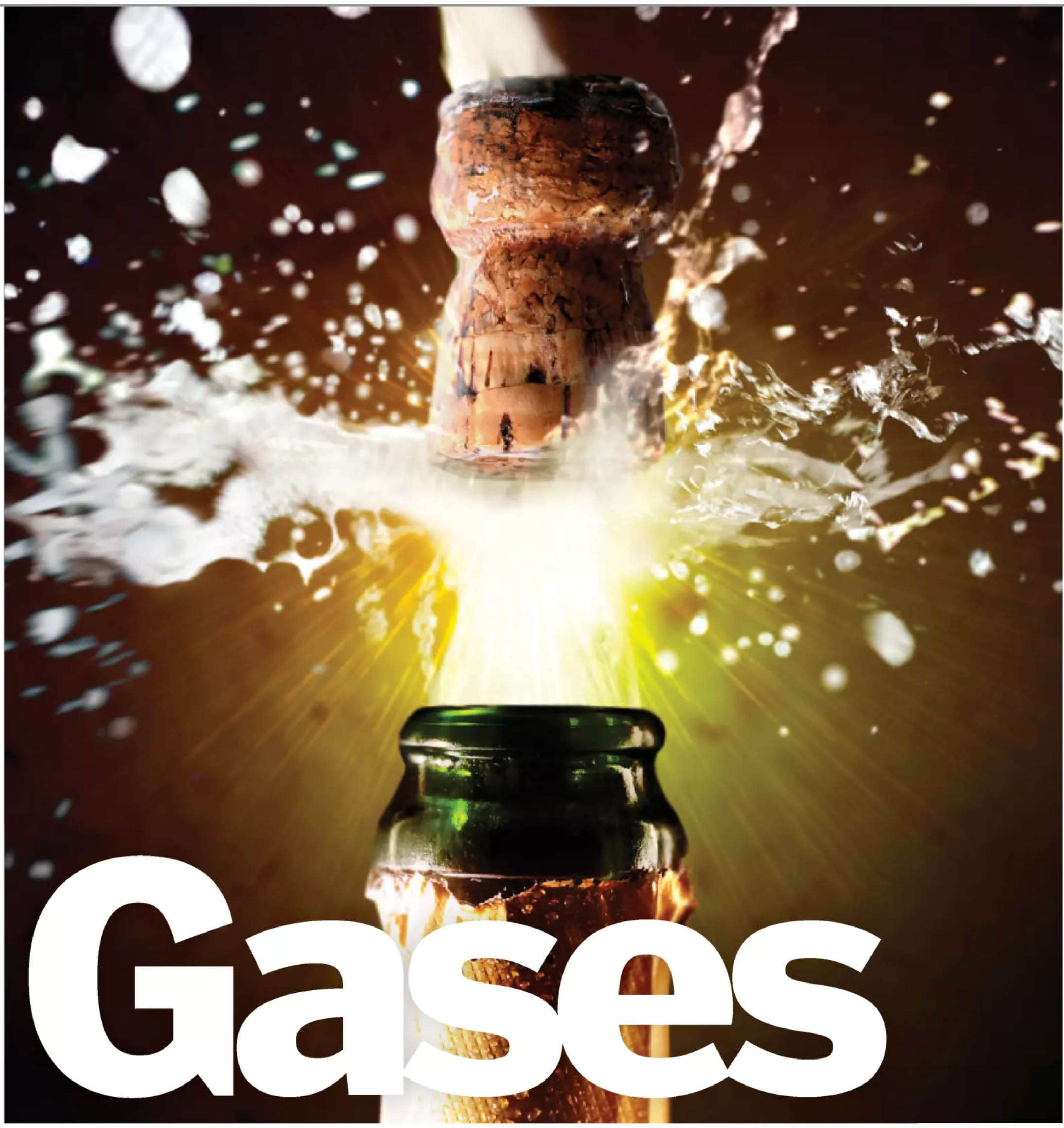
Hot-air balloons float by heating propane in its liquid state until it becomes a gas. The propane gas is ignited and expands, causing the air around it (trapped in the balloon) to heat as well. Hot air is less dense than cooler air, so the balloon rises.

Compressing a gas raises its temperature and density

Compression

Compressing a gas means putting it under greater pressure, and this also results in an increase in temperature. This is because the molecules are closer together and they generate more energy as they collide with one another. Many gases are kept under specific pressures – usually higher pressure than that of the atmosphere – for use in various industries.

Basic bicycle pumps function in the same way as pistons. Drawing up the handle pulls air into the valve; then the downstroke compresses the air and forces it quickly into the bicycle tyre.



Gases

This classic state of matter can be difficult to see but it has some amazing properties

Along with liquids and solids, gases are one of the three major states of matter. Typically they result when a substance is heated in its liquid state to its boiling point, or when evaporation occurs from the surface of a liquid. There are numerous types and classifications of gases, including elements that naturally exist in a gaseous form, compound gases comprising more than one element, and mixtures of individual pure gases (such as air).

Gas particles are much more loosely connected than those found in liquid or solid states, which results in lower density – and this is ultimately what sets a gas apart from the other two phases. Without changes in pressure or temperature, gas particles move around freely and randomly. They have no set shape and only change direction and momentum when bouncing off one another or off the inside of a container. Negatively charged areas of particles are attracted to positively charged areas – how these interact varies depending on the gas and are part of what makes each one unique. Because most gases are colourless, they are measured by four different properties: volume, temperature, pressure and number of particles; the latter property is more commonly known as moles. When put into a container (and not pressurised) gas molecules will evenly distribute themselves.

Like liquids, gases will morph into any container, however gas particles will distribute themselves evenly

1. INERT


Helium
Application: Cooling superconducting magnets
This has the lowest boiling and melting points of any element, and it's one of the most abundant.

2. REACTIVE


Ozone
Application: Disinfectant
Unstable ozone burns super fast with just a small spark. It's also very reactive, oxidising most metals and more.

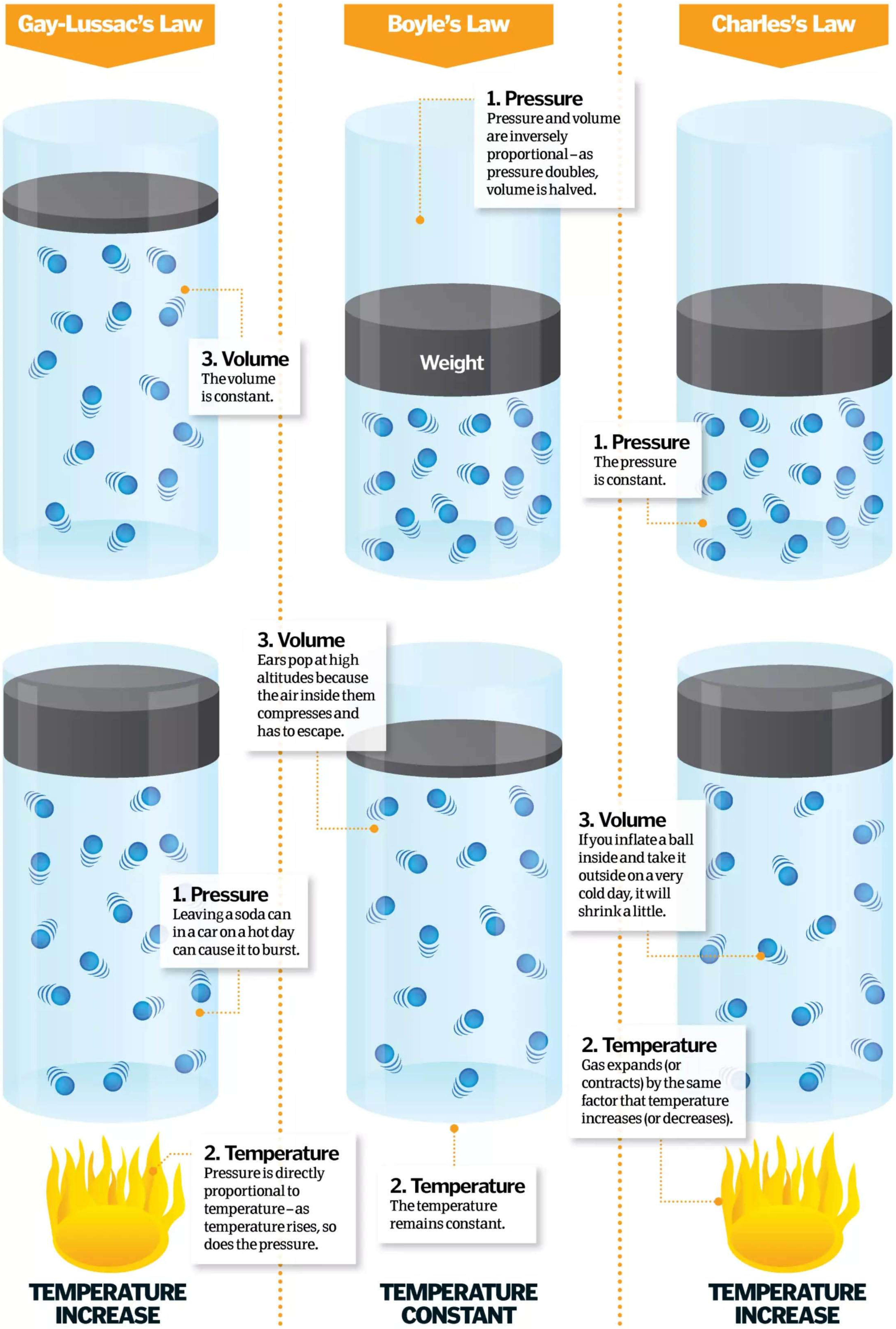
3. MOST REACTIVE


Fluorine
Application: Refrigerants
This poisonous gas can be explosively or violently reactive, even when mixed with non-reactive substances like water.

DID YOU KNOW? *We think of the air that we breathe as mostly oxygen, but it is actually about 75 per cent nitrogen*

Understanding the behaviour of gases

Gen up on the laws that govern this state of matter



More gas particle collisions make for greater pressure

Under pressure

When a gas is under pressure in a container, it's exerting force against the inside of that container. Gas particles travel around in straight lines until they collide with one another and the walls of the object holding them; this changes their momentum and creates pressure.

If you shake a can of soda before opening it, you'll have quite a mess; this is a result of the carbon dioxide gas sitting on top of the soda, along with the gas that's dissolved in the liquid itself. Shaking it forces the extra gas into the liquid, creating large bubbles that rapidly push their way out as you open the can.


Vapour is a sort of halfway point between gas and liquid states

Vapour

Vapour is a gaseous phase in which a substance is at a slightly lower temperature than its critical point – the conditions, like temperature and pressure, under which it changes to a different state of matter. When it reaches its critical point, it can be condensed. A vapour, therefore, is a sort of halfway state. Substances can also exist in both states at the same time. One example of vapour occurs when boiling water. Once water reaches its boiling point, it begins to turn to a gas; in the case of boiling water, we better know the vapour as steam.

Electricity explained

Learn some shocking facts behind the everyday energy we take for granted

Many people think of electricity as something you buy from the power companies, but as well as coming out of the wall socket, electricity is one of the many ingredients that make up the universe. Read on to find out why electricity occurs, how it behaves and how it reaches your home.

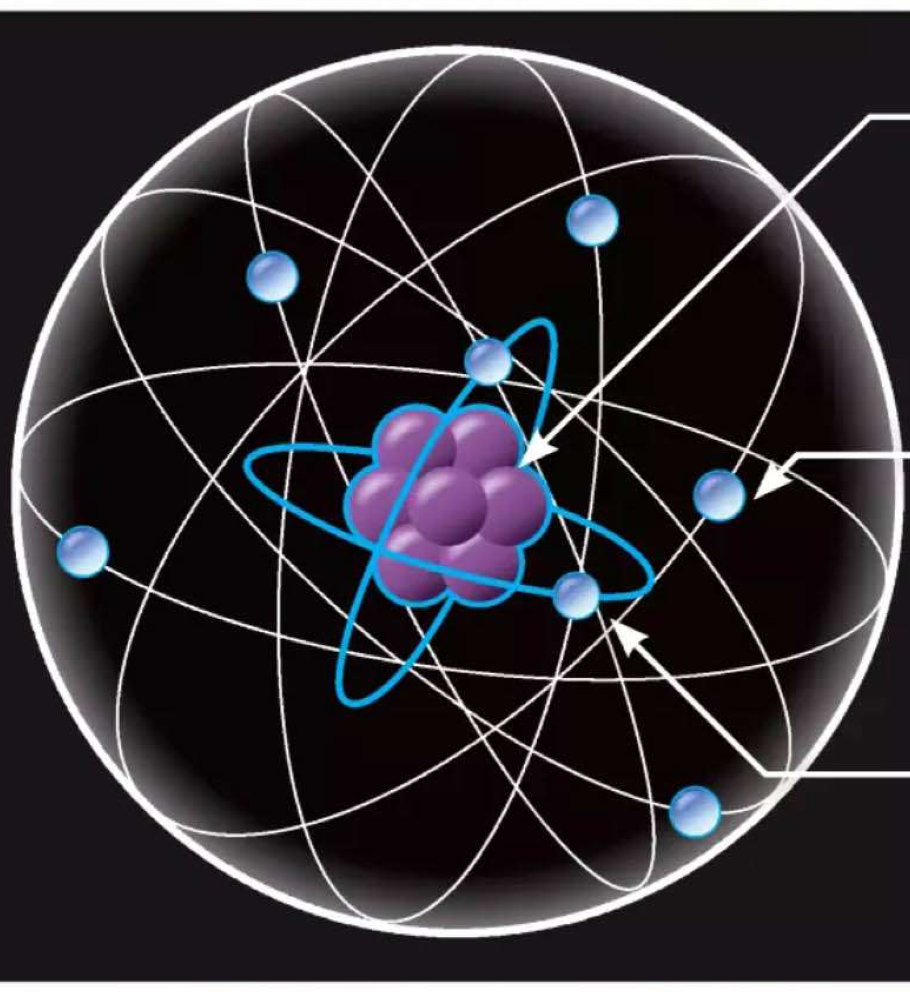
Everything in the universe is made of minuscule atoms and these atoms consist of a nucleus orbited by one or more electrons. These electrons carry a negative charge while the nucleus is positively charged.

We're all familiar with the effects of static electricity. We are not often aware of electricity around us as the positive and negative charges usually balance. When certain objects touch, however, electrons can jump between them. For instance, when you rub a balloon against your hair electrons will jump across to the balloon giving the balloon stationary negative charge or static electricity. Static electricity relies on electrons not being able to move around easily. Materials like wood, glass, ceramics and cotton all have electrons that like to stick with their atoms and because the electrons don't move the materials can't conduct electricity very well.

In most metals, electrons can move freely to form an electric current. When charges move, current electricity is formed and this is the power that drives much of the contemporary world. Current can be measured by the amount of charge passing a fixed point each second.

Inside an atom

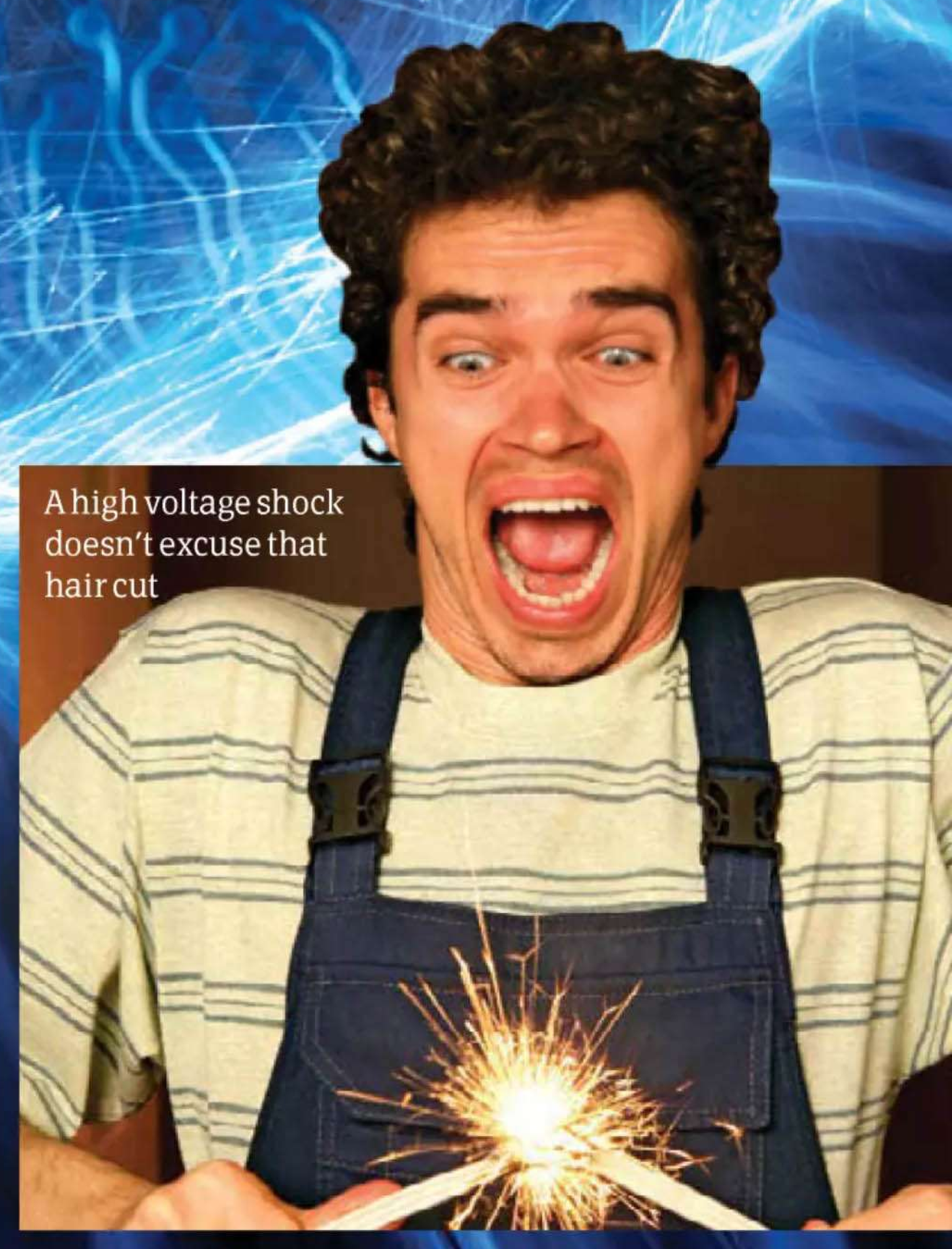
Atoms are held together by electricity. The positive nucleus attracts the negative electron. The two cancel each other out so the atom has no electric charge



1. The nucleus
The nucleus is at the centre of the atom and is positively charged

2. Negative charge
Each electron is negatively charged

3. Electrons
Electrons orbit the nucleus



A high voltage shock doesn't excuse that hair cut

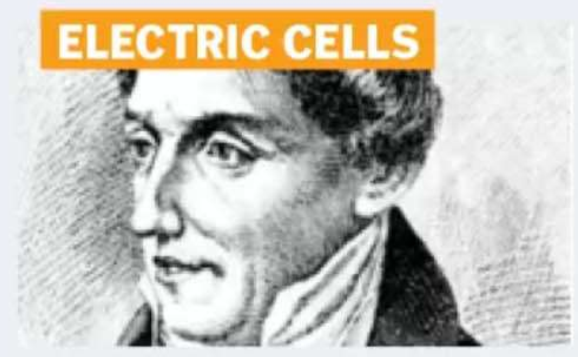
THE WORD

William Gilbert
Scientist and physician to Queen Elizabeth I, he invented the term and was the first to describe the earth's magnetic field.

LIGHTNING ROD

Benjamin Franklin
Flew a kite with a metal key attached into a thunderstorm to prove that lightning is a form of electricity.

ELECTRIC CELLS



Alessandro Volta
This Italian scientist's experiment using soaked paper in salt water, zinc and copper created the first electric cell.

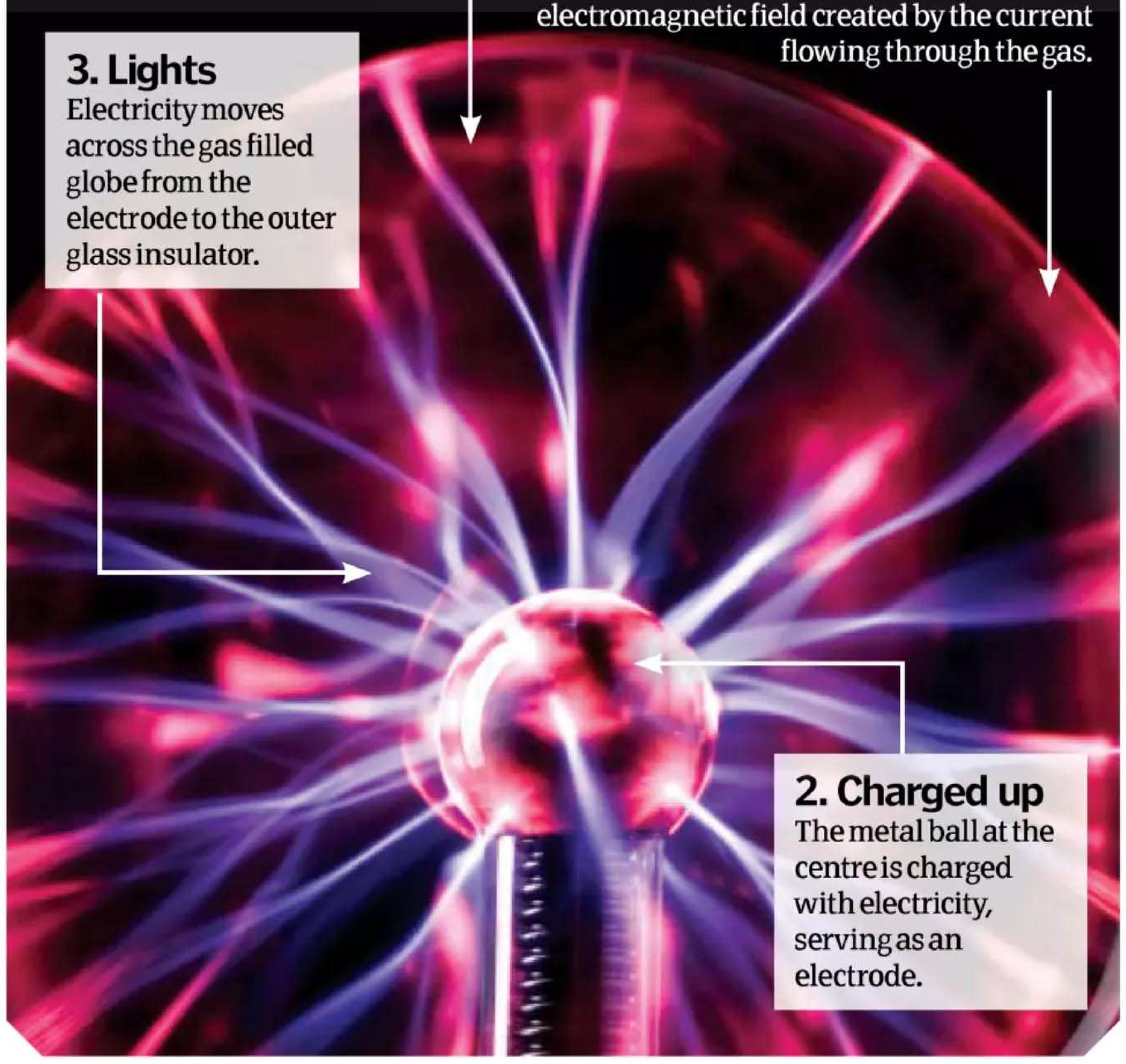
DID YOU KNOW? *The word 'electricity' is derived from the Greek word for amber, elektron*

Plasma balls – static incarnate

They went out of fashion in the Eighties but still demonstrate electricity really well

1. Full of gas
The glass ball is filled with a mixture of gases, usually helium and neon, at low pressure.

4. Touch the power
Placing your hand on the glass alters the electric field and causes a single beam to migrate from the inner ball to the point of contact, the glass does not block the electromagnetic field created by the current flowing through the gas.



3. Lights
Electricity moves across the gas filled globe from the electrode to the outer glass insulator.

2. Charged up
The metal ball at the centre is charged with electricity, serving as an electrode.

Conductors

Very simply, a conductor is a material that allows electric charge to pass along it as a current. As stated, metals make good conductors as the electrons of their atoms are loosely bound and free to move through the material. For instance, in copper the electrons are essentially free and strongly repel each other. Any external influence that moves one of them will be replicated through the material.

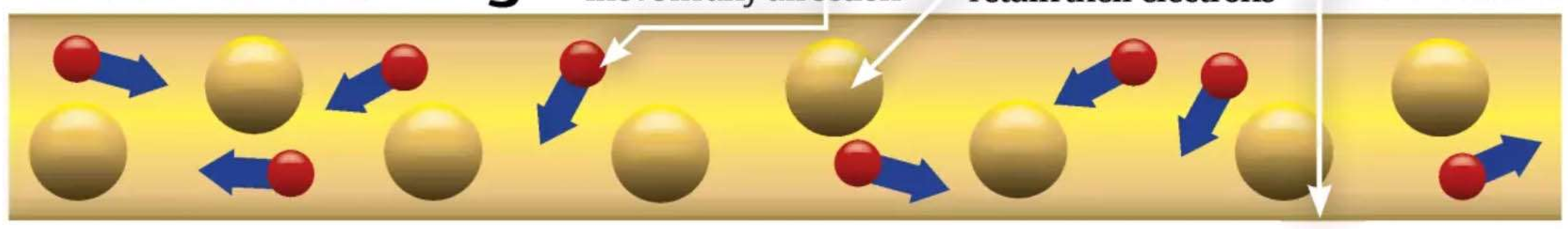
A superconductor is a material that has no resistance at all to the flow of current when kept below a certain temperature. For most superconducting materials, the critical temperature is below about 30K (30°C above absolute zero).

No current flowing

These free electrons can move in any direction

The copper atoms retain their electrons

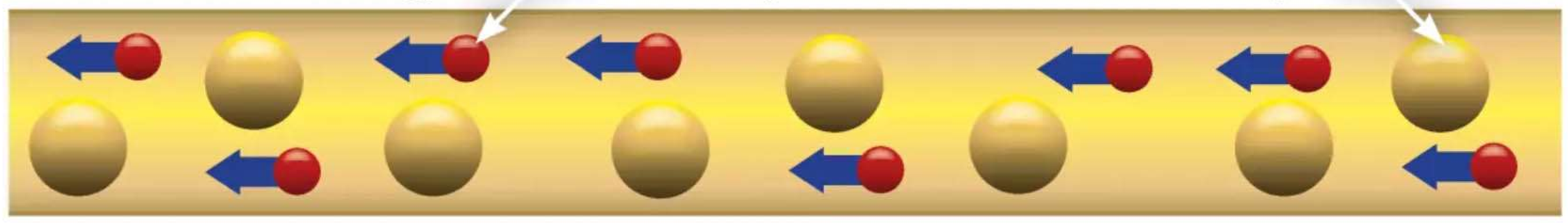
Wire surface



Current flowing

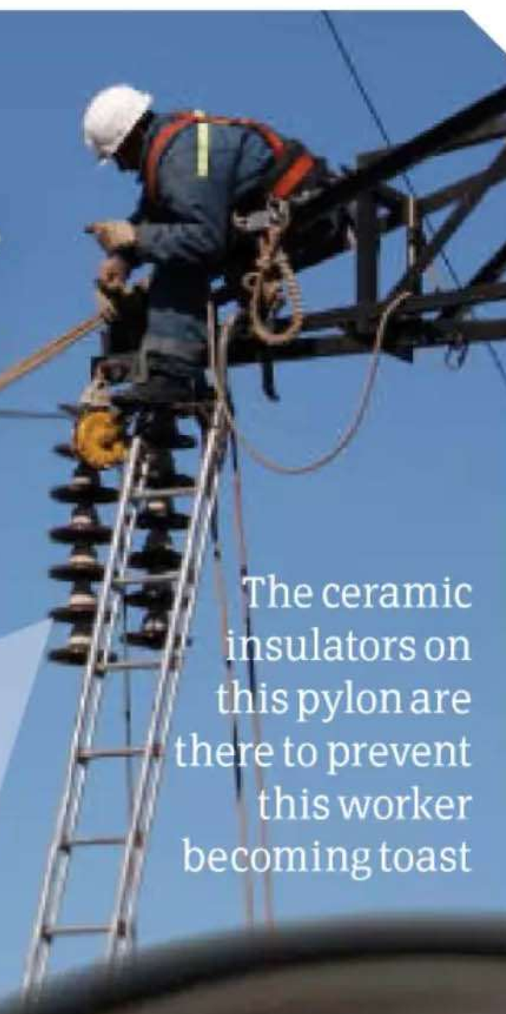
The free electrons move towards the positive terminal

The copper atom remains in placc



Insulators

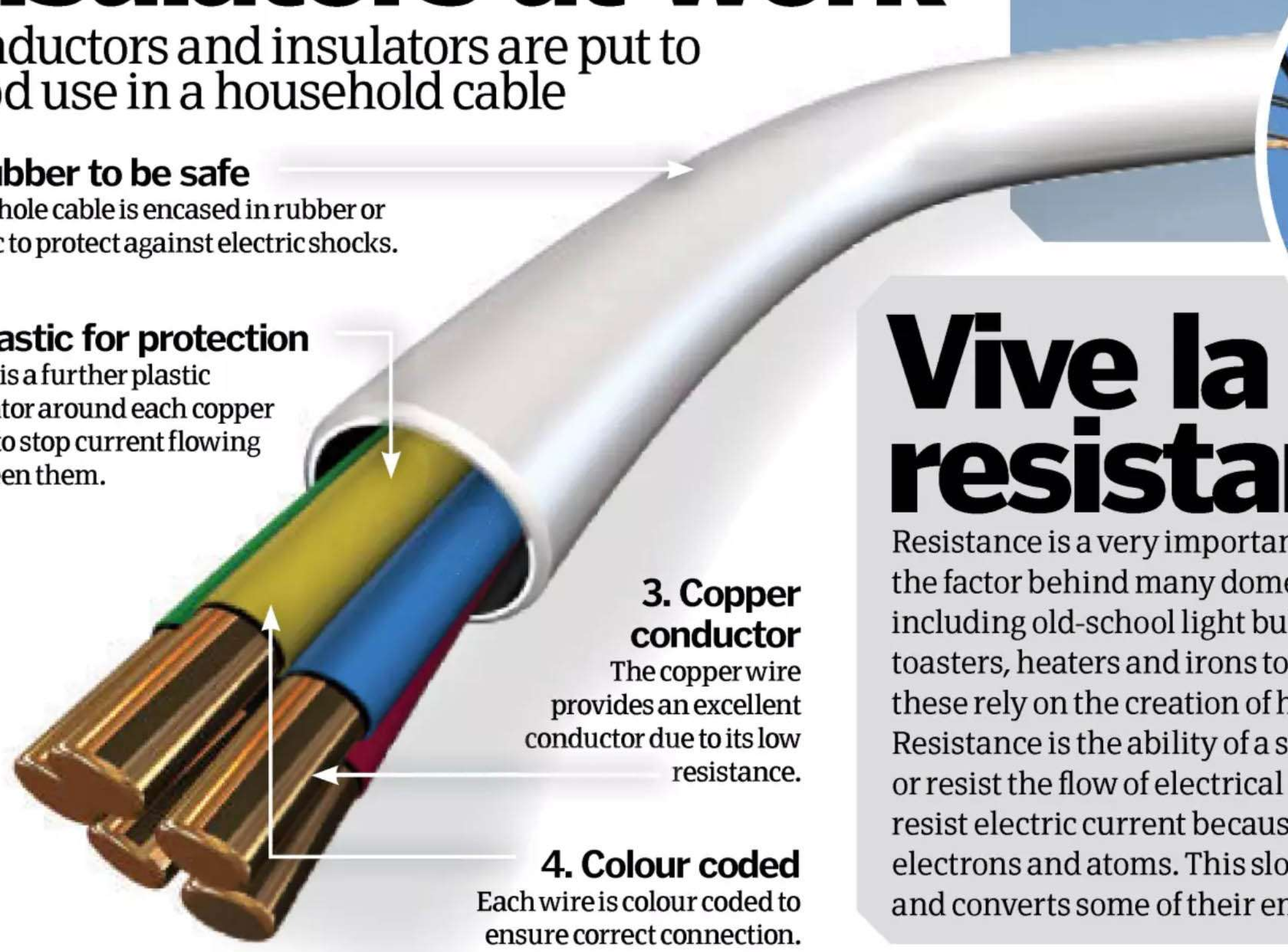
Insulators are materials that have the exact opposite effect on the flow of electrons. Their atoms have tightly bound electrons which are not free to roam around. That said, insulators can still play an important role in the flow of electricity by protecting us from the dangerous effects of a current flowing through conductors. If the voltage is high enough an electric current can be made to flow through a material that is not a good conductor, like the human body. The function of our hearts can be affected by an electric shock and the heat generated by the current can cause burns.



The ceramic insulators on this pylon are there to prevent this worker becoming toast

Conductors and insulators at work

Conductors and insulators are put to good use in a household cable



1. Rubber to be safe
The whole cable is encased in rubber or plastic to protect against electric shocks.

2. Plastic for protection
There is a further plastic insulator around each copper cable to stop current flowing between them.

3. Copper conductor
The copper wire provides an excellent conductor due to its low resistance.

4. Colour coded
Each wire is colour coded to ensure correct connection.

Vive la resistance

Resistance is a very important property, it's the factor behind many domestic appliances including old-school light bulbs, kettles, toasters, heaters and irons to name a few. All these rely on the creation of heat energy. Resistance is the ability of a substance to prevent or resist the flow of electrical current. Materials resist electric current because of a collision between electrons and atoms. This slows the electrons down and converts some of their energy to heat energy.

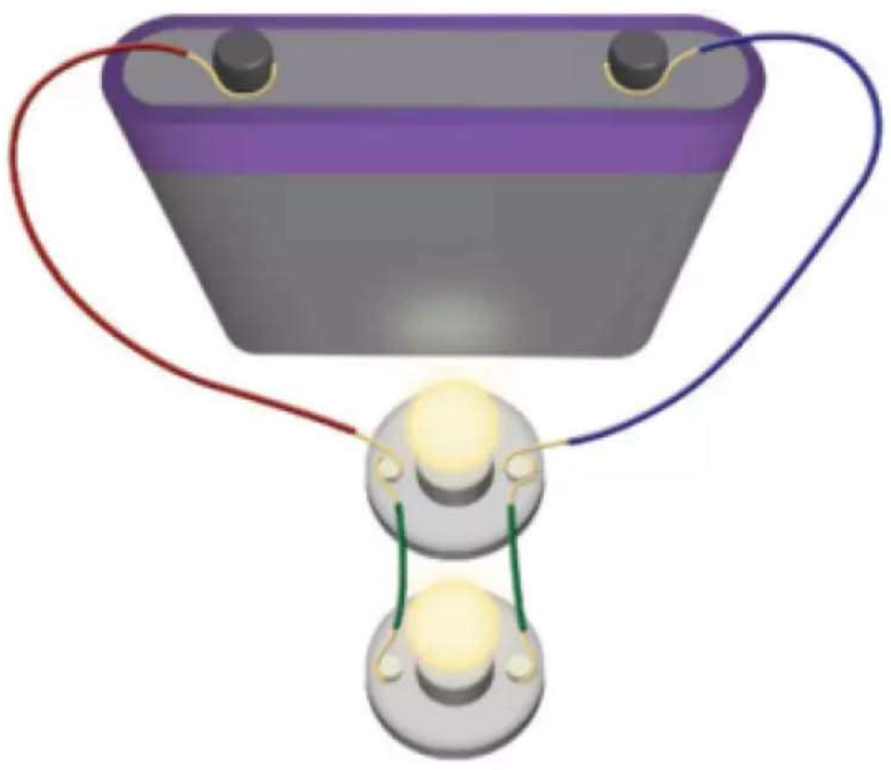
An electric current passes through a thin filament, heating it so that it produces light

> "Electricity can't do a lot of work without circuits as these provide a path for the electricity to flow around"

Circuits

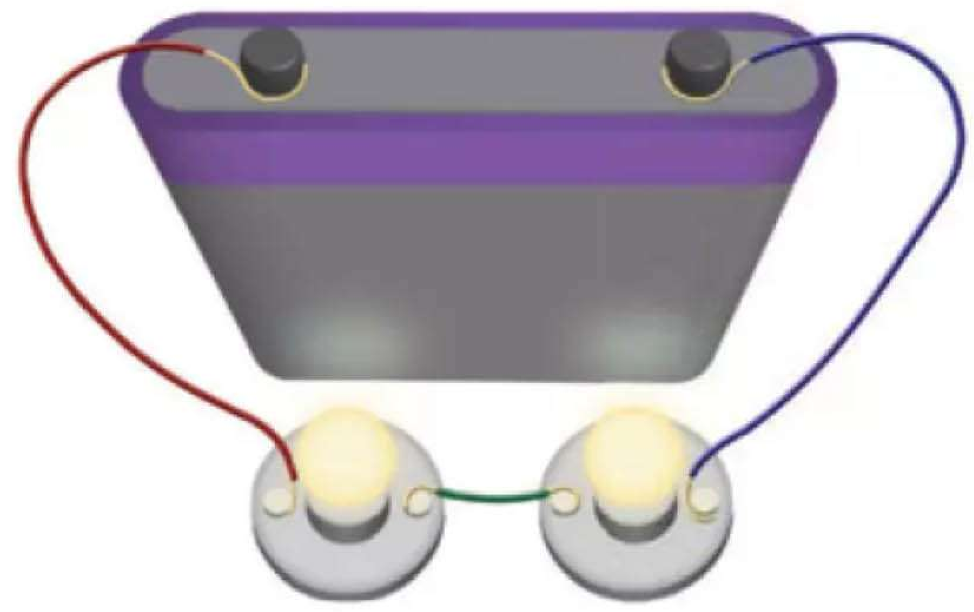
Putting electricity to work all over the world

Now that we've explained where electricity comes from it's time to look at some of the work it can do for us. Electricity can't do a lot of work without circuits as these provide a path for the electricity to flow around. Circuits include devices such as resistors, which control the flow of voltage, or difference in electrical charge, and capacitors, which store electrical charge and come in one of two types, series and parallel.



Parallel circuits

In a parallel circuit there is more than one pathway between its beginning and end. Since the electricity has more than one route to take, the circuit can still function should one component fail. This means that parallel circuits are much less prone to failure than the series variety. For this reason parallel circuits are the kind you will find in most everyday applications such as domestic appliances and household wiring.



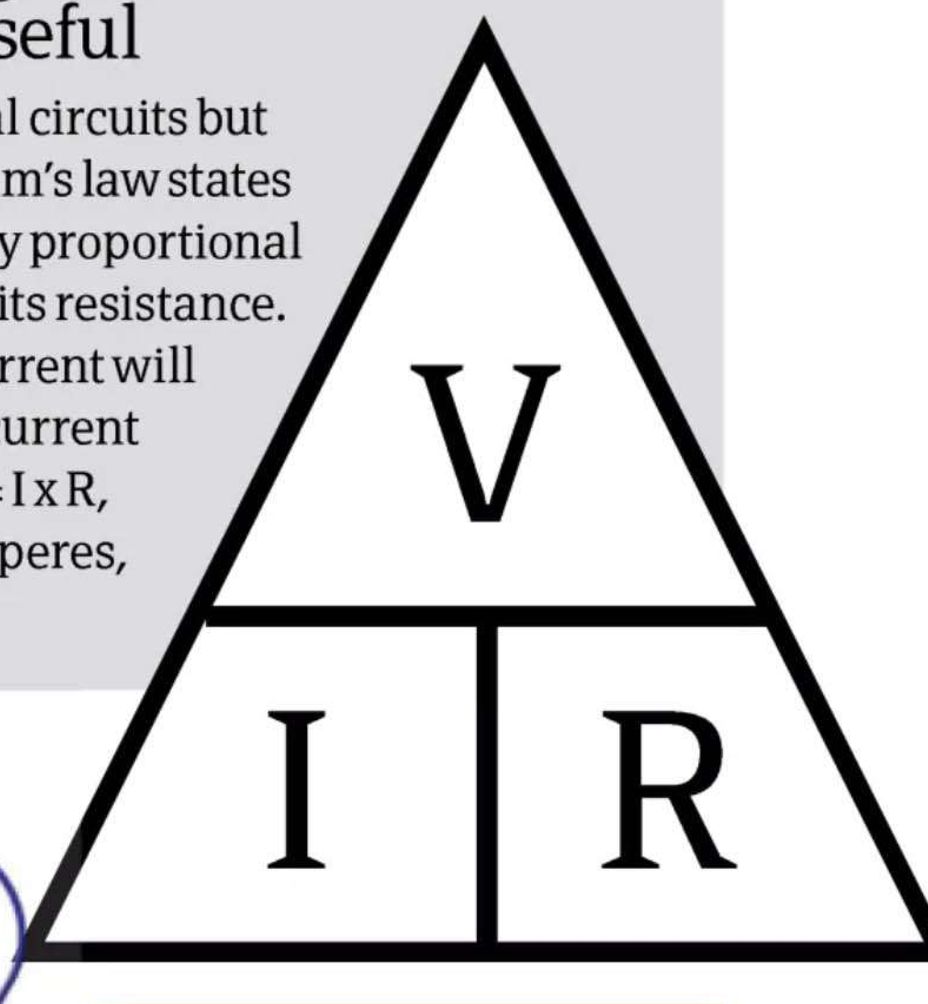
Series circuits

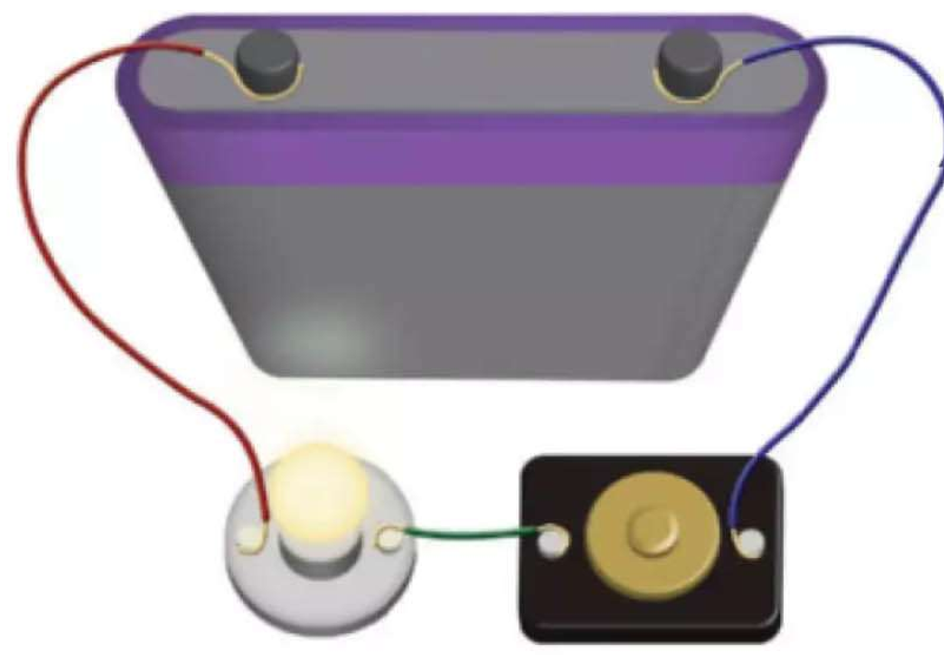
A series circuit has more than one resistor and only has one path for the charges to move along. A resistor is anything that uses electricity to do work (in this case, light bulbs) and the electric charge must move in series from one resistor to the next. If one of the components in the circuit is broken then no charge can move through it. An example of a series circuit is old-style Christmas lights, if one bulb breaks the whole string goes out.

Laws of circuits

Ohm's triangle; not as exciting as the Bermuda triangle but more useful

There are many laws that apply to electrical circuits but Ohm's law is one of the most important. Ohm's law states that an electrical circuit's current is directly proportional to its voltage and inversely proportional to its resistance. So, if voltage increases, for example, the current will also increase, and if resistance increases, current decreases. The formula for Ohm's law is V = I x R, where V = voltage in volts, I = current in amperes, and R = resistance in ohms.





Circuit control

The simplest electrical control is a switch. This simply breaks the circuit to stop the current flowing and this is most notably seen in domestic light switches. They may seem simple, but the most complex computers are made from millions of electronically controlled switches.

CIRCUIT JARGON

Current
The flow of an electric charge. Unit Volt, symbol V.

Voltage
Or electrical potential difference, the force that drives the current in one direction. Unit Ampere, symbol A.

Resistance
The opposition of an object to having current pass through it. Unit Ohm, symbol Ω.

How electricity reaches your home

It's taken for granted that the light will come on when you hit the switch, here's how the power gets to your house

1. Coal or nuclear
Coal is burnt at the electricity plant to generate steam. Nuclear power stations use a different method (see issue 3) so do hydroelectric plants (see issue 2).

2. Generation X
Be it nuclear, coal-fired or hydro a turbine spins a huge magnet inside a copper wire. Heat energy converts to mechanical energy which then converts to electrical energy in the generator.

3. Danger! High voltage!
The electricity then flows though heavily insulated wires to a step-up transformer. This raises the pressure so it can travel long distances over the grid. It's raised as high as 756,000 volts.

4. Transform it
The electricity then runs along the power lines until it reaches a substation. This lowers the pressure to around 2,000-13,000 volts.

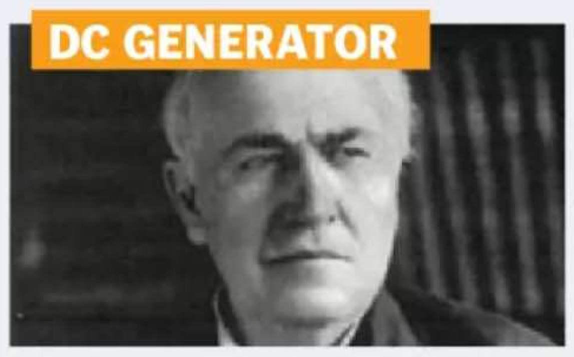
5. Pylon it up
The current continues along the lines to another transformer, either a pole transformer or an underground box, and pressure is lowered again to between 120 and 240 volts.

6. Service with a spark
The next stop is the service box at your home. Here your meter will measure how much power you use. Wires then take the electricity around your home powering your lights and everything else.

ELECTRIC MOTORS

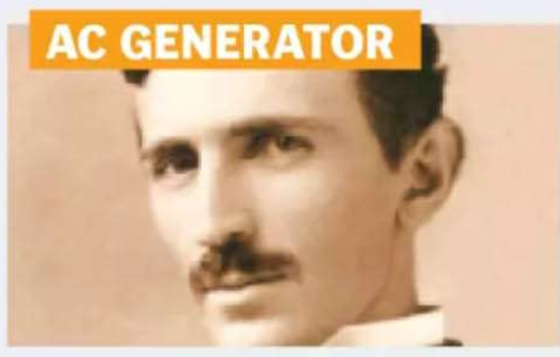
Michael Faraday
Faraday discovered that when a magnet is moved inside a coil of copper wire, an electric current flows through the wire.

DC GENERATOR



Thomas Edison
Edison built a DC (direct current) electric generator in America. He later provided all of New York's electricity.

AC GENERATOR



Alessandro Volta
Developed an AC motor and a system of AC power generation. This became the established power supply in the USA.

DID YOU KNOW? Edison saw Tesla's system as a threat to his DC supply and spread stories that it wasn't safe

Electricity in your home

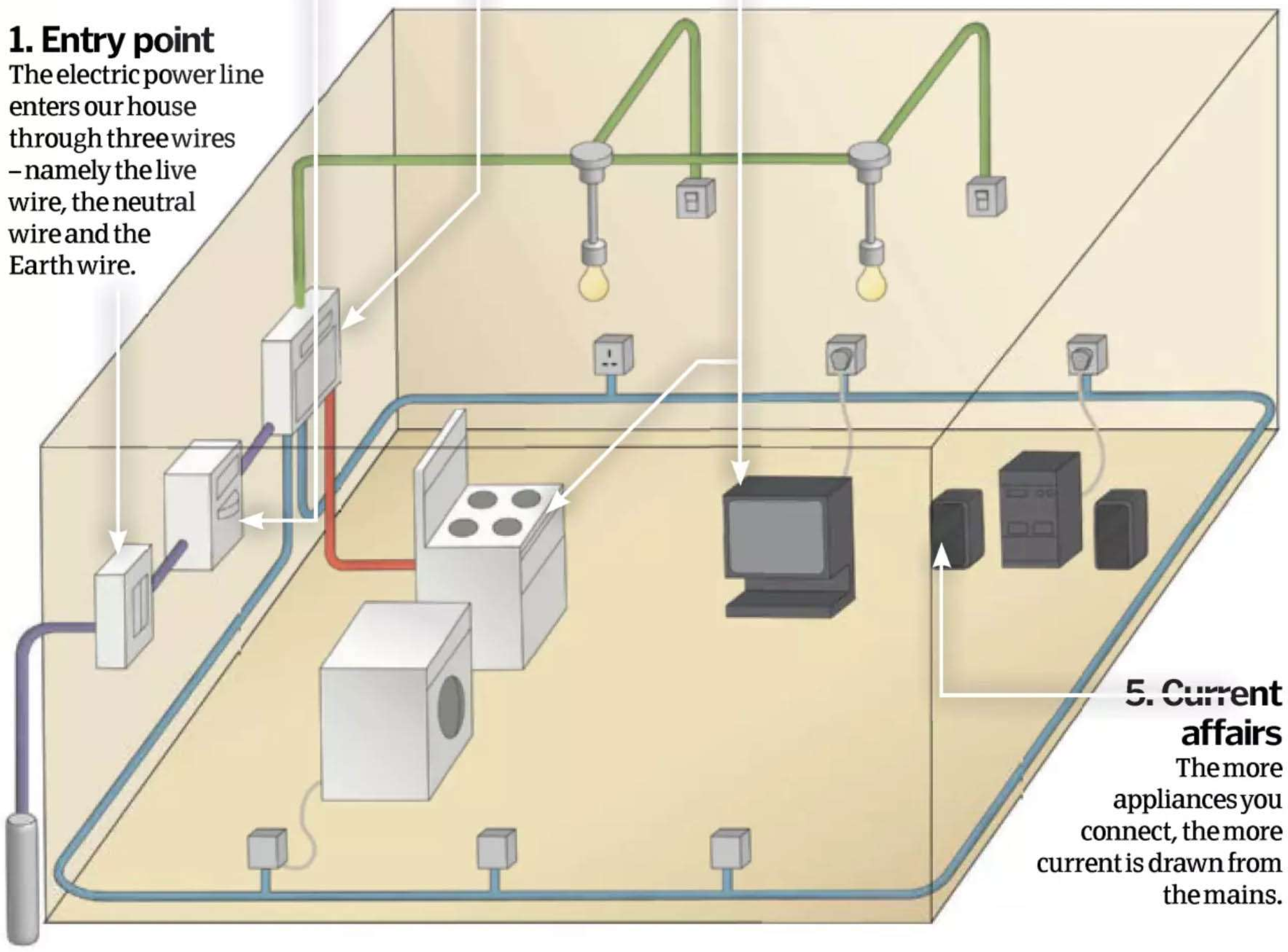
Once electricity reaches your home, how does it get around?

2. Electricity meter
Electricity meters are typically calibrated in billing units, the most common one being the kilowatt hour. Periodic readings of electric meters establishes billing cycles and energy used during a cycle.

3. Distribution box
This contains the main switch and fuses for each circuit.

4. Appliances of science
Domestic appliances are connected in parallel. In a parallel circuit even if there is a fault or short-circuiting in any one line, the corresponding fuse blows off, leaving the other circuits and appliances intact and prevents damage to the entire house.

1. Entry point
The electric power line enters our house through three wires – namely the live wire, the neutral wire and the Earth wire.



5. Current affairs
The more appliances you connect, the more current is drawn from the mains.

The only thing shocking about AC/DC these days is Angus Young's shorts!

All about AC/DC

As we've seen, the word electricity is derived from the fact that current is electrons moving along a conductor that have been harnessed for energy. The difference between Alternating Current (AC) and Direct Current (DC) is related to the direction in which the electrons flow. In DC the electrons flow steadily in a single 'forward' direction. In AC electrons keep switching directions. The power supplied by electricity companies is AC because it's much easier to transport across long distances, it can easily be stepped up to a higher voltage with a transformer. It's also more efficient to send along power lines before being stepped down by another transformer at the customer's end.

Why are British plugs so big?

We owe our plugs to World War Two

Visitors to and natives of the British Isles get to use one of the weirdest plugs in the world; unlike many other plugs it has a fuse built in. After being bombed heavily by the Germans during WW2, much of the country had to be rebuilt. Building supplies were short so rather than wiring each socket to a fuseboard they were linked together on one wire and the fuses put in each plug, saving a great deal of copper in the process.

1. Ground to Earth
The Earth wire is there to prevent electric shock and is secured by a screw terminal.

2. Fused
The fuse is designed to blow and break the circuit if the appliance gets too much current.

Inside a British plug

Why do all countries have different plugs?

"Dammit, all I wanted was a %$**@* shave!"

Even more than baggage handling and passport control, one of the biggest problems faced by the frequent traveller is the fact that every country in the world has different plugs. In the US, shortly after the AC/DC battle had been resolved (AC won) a man named Harvey Hubbell invented the two pin plug "so that electrical power in buildings may be utilised by persons having no electrical knowledge or skill" (his words). This was later developed into a three pin plug by Philip Labre in 1928 with the third pin for grounding. At the same time developments like this were occurring all around the world with absolutely no global-standardisation. There was some effort made by the International Electrotechnical Commission shortly before the Second World War occurred and spoilt it all!

Two pin or three pin? It depends where you are!

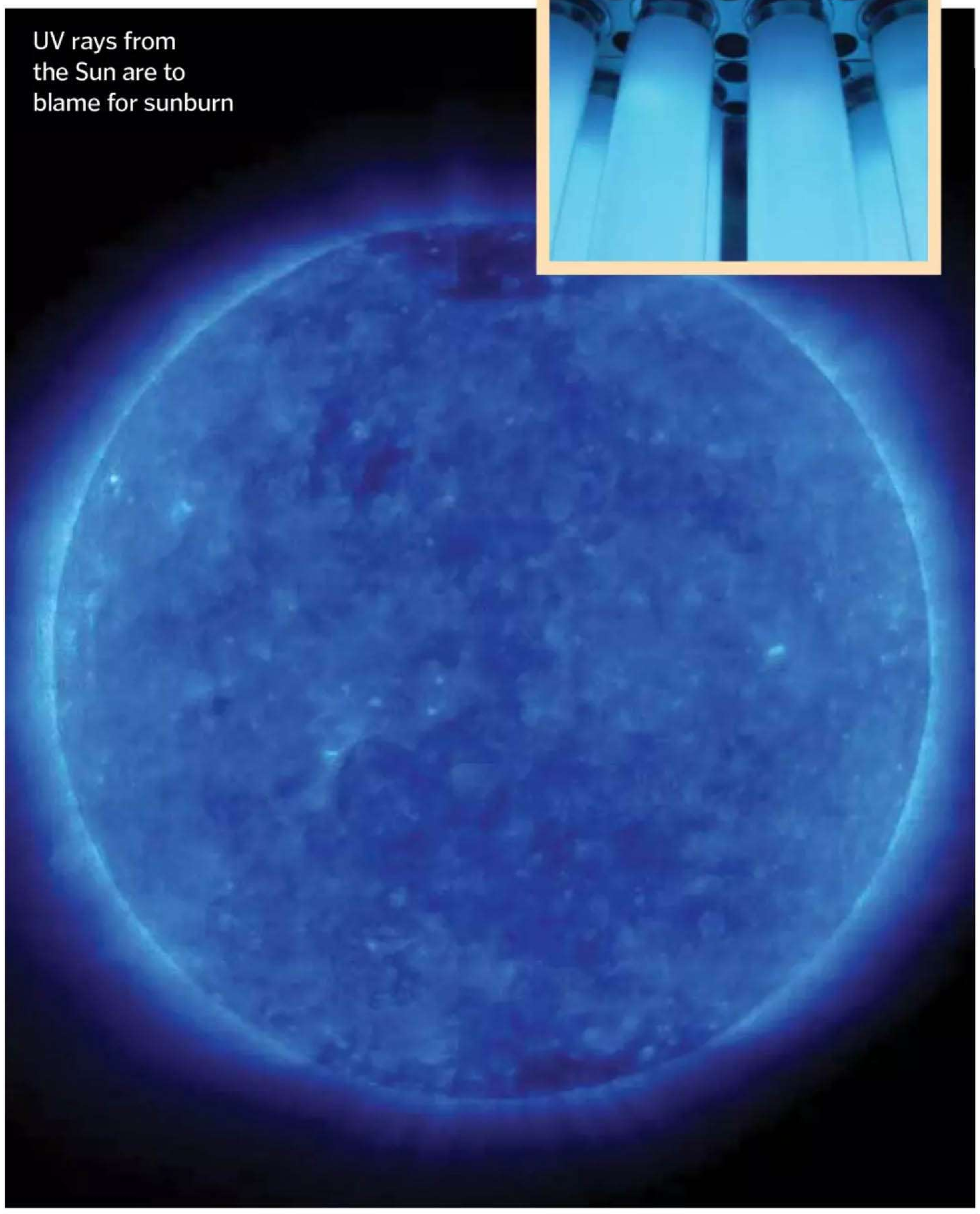
Understanding ultraviolet

Discover what this form of electromagnetic radiation is all about

Ultraviolet (UV) radiation is a part of the electromagnetic spectrum that extends from the end of visible light through to X-rays. This part of the spectrum is undetectable to the naked eye, with only a few insects capable of seeing it, but it's indirectly visible to us via fluorescent objects, which emit the radiation at a lower energy level.

The spectrum of ultraviolet light lies between the wavelengths of 400 nanometres (near-visible light) through to just ten nanometres (near-X-ray). This spectrum is divided into four major categories: near (400-300 nanometres), middle (300-200 nanometres), far (200-100 nanometres) and extreme (100-10 nanometres). It's also split into ten subtypes, which possess different qualities for various applications.

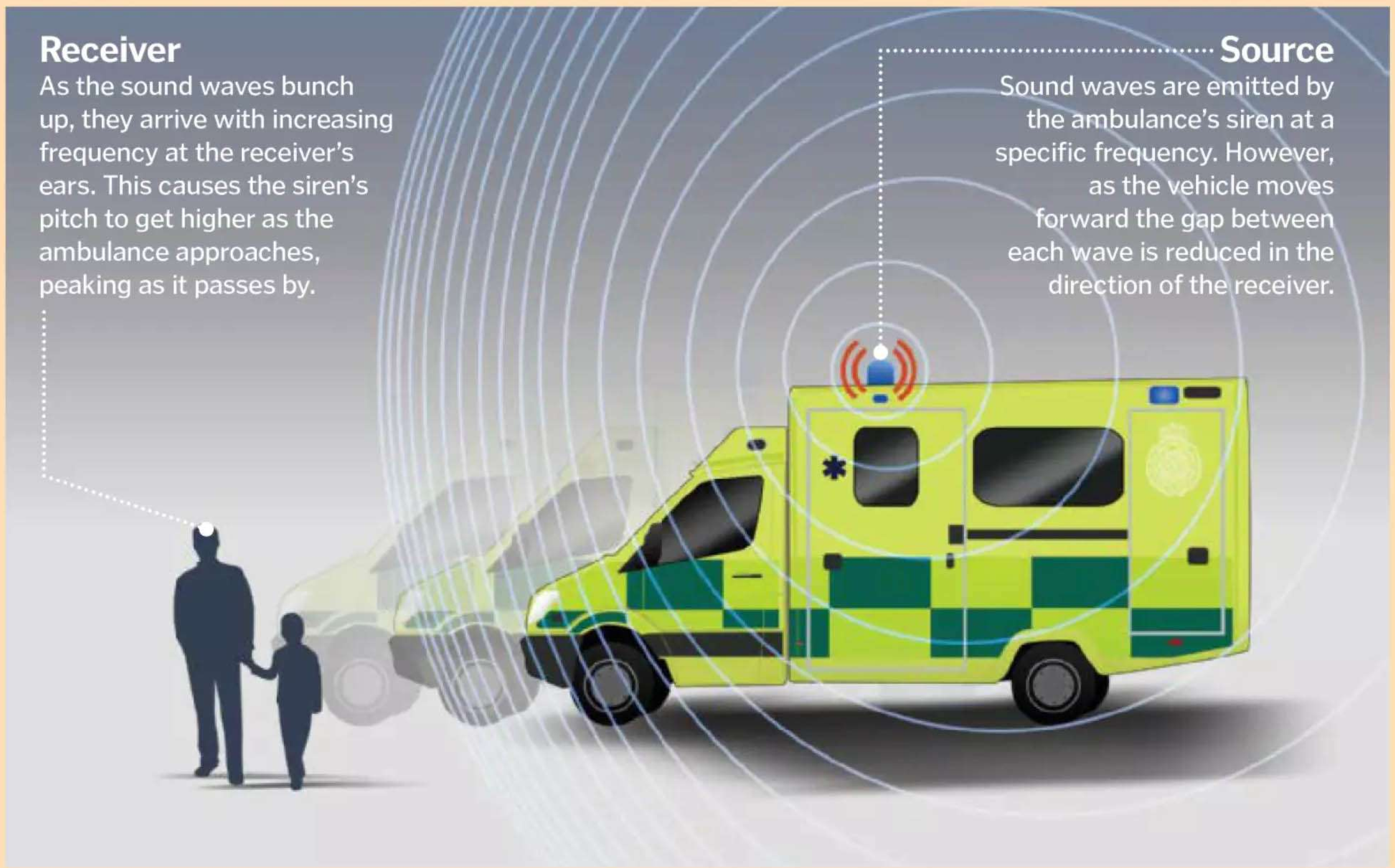
UV radiation is produced by high-temperature surfaces, such as stars, and is emitted in a continuous spectrum. On our planet, for example, the majority of UV light is found in light rays emanating from the Sun, where it constitutes about ten per cent when in the near-vacuum of space. However, the vast majority of this UV radiation is absorbed by ozone in the Earth's atmosphere, with only limited quantities of the ultraviolet A (UVA) subtype reaching the surface.


UV rays from the Sun are to blame for sunburn

Understanding the Doppler effect

Discover why the sound of a siren or F1 car changes depending on its proximity

The Doppler effect – named after Austrian physicist Christian Doppler – is the perceived difference between the frequency at which sound, or light, waves emanate from a source and at which they are received. A good everyday example is an ambulance approaching a pedestrian. The vehicle's siren emits sound waves at a certain frequency, which if both the ambulance and person were stationary would remain at a constant pitch. But, as the vehicle speeds towards the person, the pitch gets ever higher until it passes, lowering again as it recedes. The reason for this shift is that, due to the motion of the ambulance, the sound waves bunch up, taking less and less time to reach the pedestrian's ears . This bunching up effect increases the number of waves reaching the receiver at once, leading to an apparent fluctuation in pitch.



DID YOU KNOW? *Brazilian Didi was the first top-level footballer to master the curling free kick, called the dry leaf technique*

The physics of football

Discover the science that lies behind taking the perfect free kick

The likes of David Beckham and Cristiano Ronaldo are known around the world for their expertise in the art of the free kick. Whether it's a curler into the top corner or a thundering piledriver, free kick taking is a vital part of the modern game. But how does science come into scoring a goal?

The guiding principle is the Magnus effect. Investigated by German physicist Heinrich Gustav Magnus, this law of physics demonstrates that airflow is distorted around any spinning cylinder or sphere in a certain way.

If the ball is spinning anticlockwise, the left side of it will experience less drag as it moves in the same direction as the airflow, while the right side spins against the onrushing air, increasing the drag. This creates a pressure imbalance, with the right side of the ball experiencing higher pressure and the left side experiencing lower pressure. It is this imbalance which forces the ball to move to the area with lower pressure, thus curling to the left.

But the Cristiano Ronaldo or Gareth Bale style of free kicks is a whole different ball game. The idea behind the immensely powerful, swerving free kick is imparting as little spin as possible. As the air flows over the ball, a boundary layer is produced, which is a cushion of air that sticks very tightly to the surface of the ball. If an imperfection in the ball disrupts this airflow, it will deviate in the air.

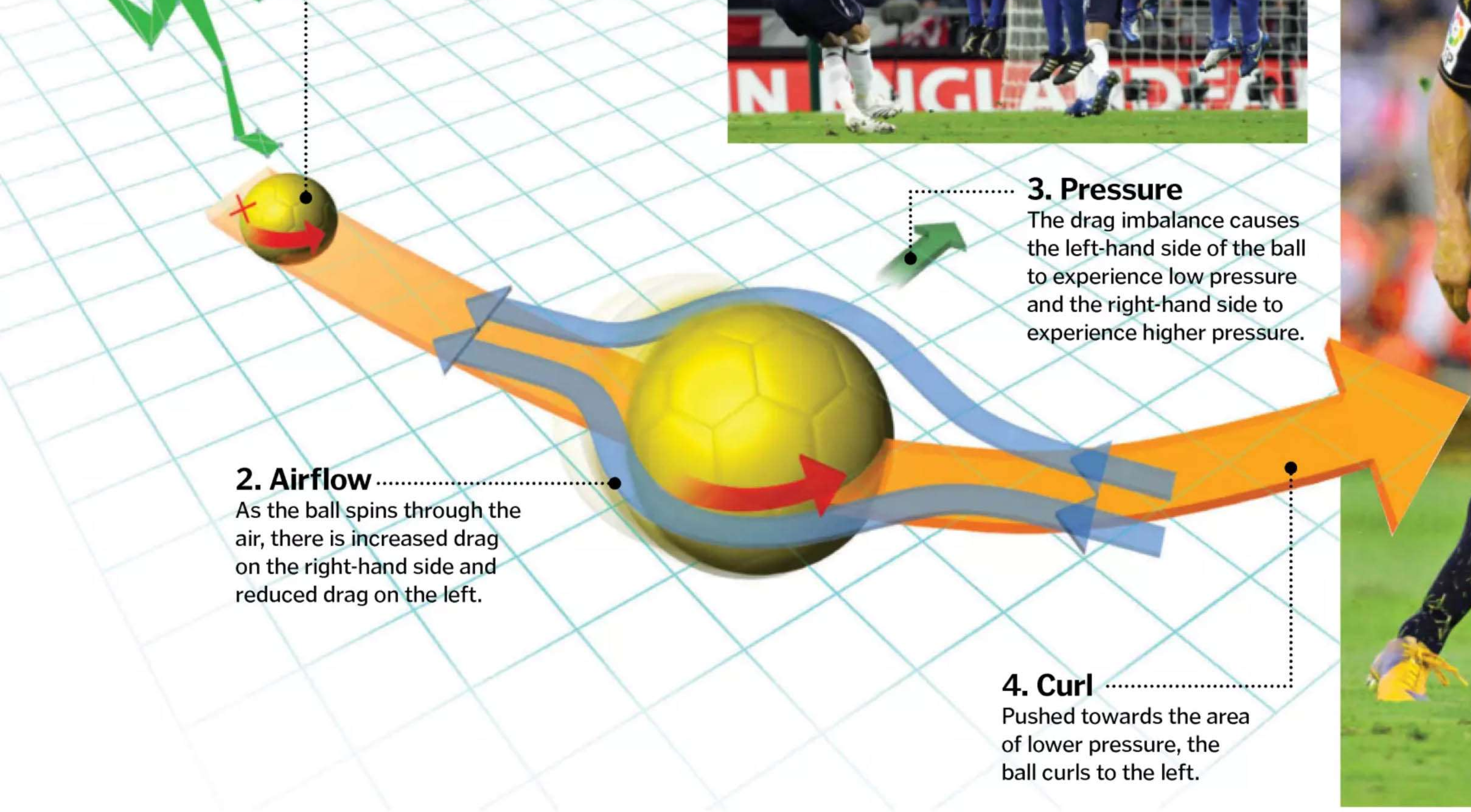
A rapidly spinning football won't deviate much, but a ball hit flatly will, as it will have more time to move in the direction of the disruption. So when Ronaldo strikes the ball with little spin, any minor imperfection in the football will cause it to move during flight and outfox many a poor, bewildered goalkeeper.

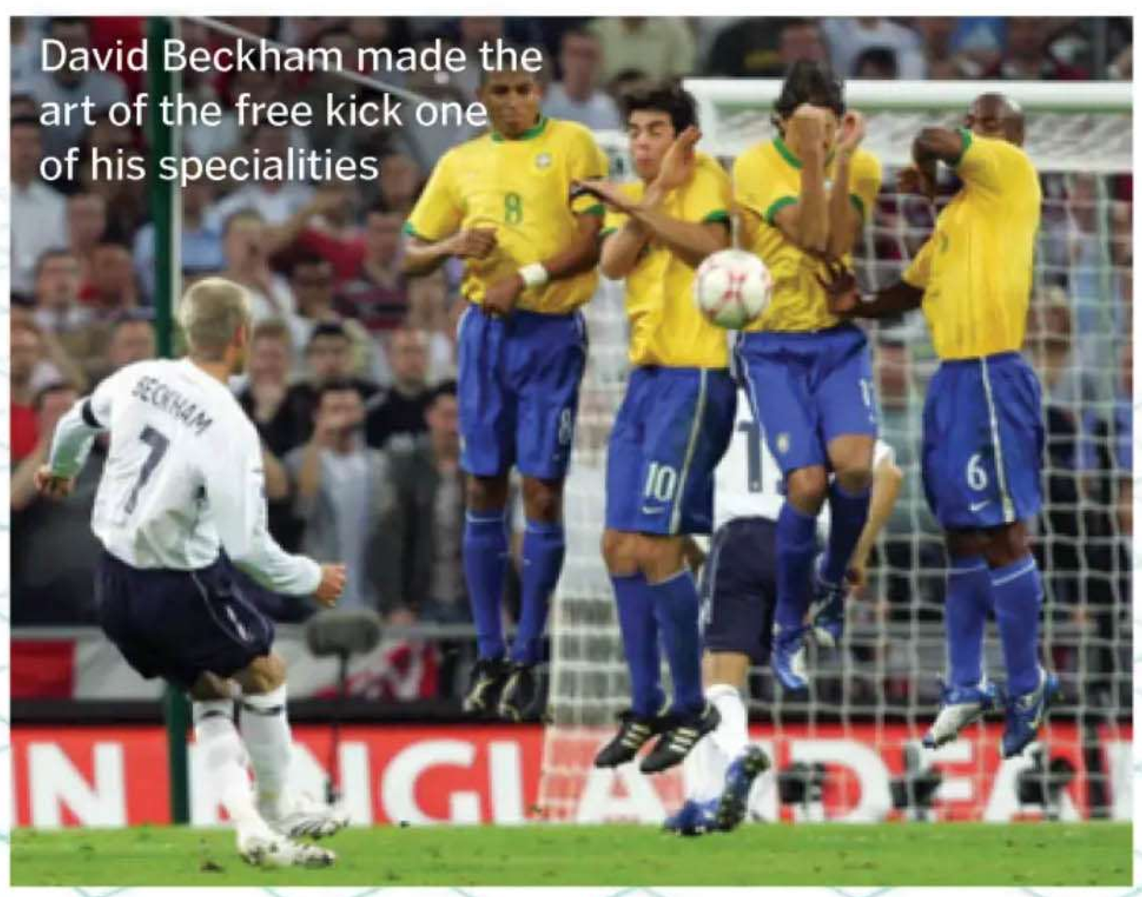
Why footballs can be too round

The official match ball for the 2010 World Cup in South Africa, known as the Jabulani, caused consternation with goalkeepers and strikers alike. The lack of panels on the ball and the use of internal stitching made it the roundest ball ever. However, the roundness of the ball caused a lot of confusion among players because of its completely unpredictable swerving. Outfield players didn't like it because the lack of imperfections meant less grip between ball and foot, meaning that they struggled to impart spin on the ball. Meanwhile, goalkeepers couldn't anticipate the trajectory because it would have a habit of suddenly slowing mid-flight or ballooning up, a bit like a plastic inflatable ball.

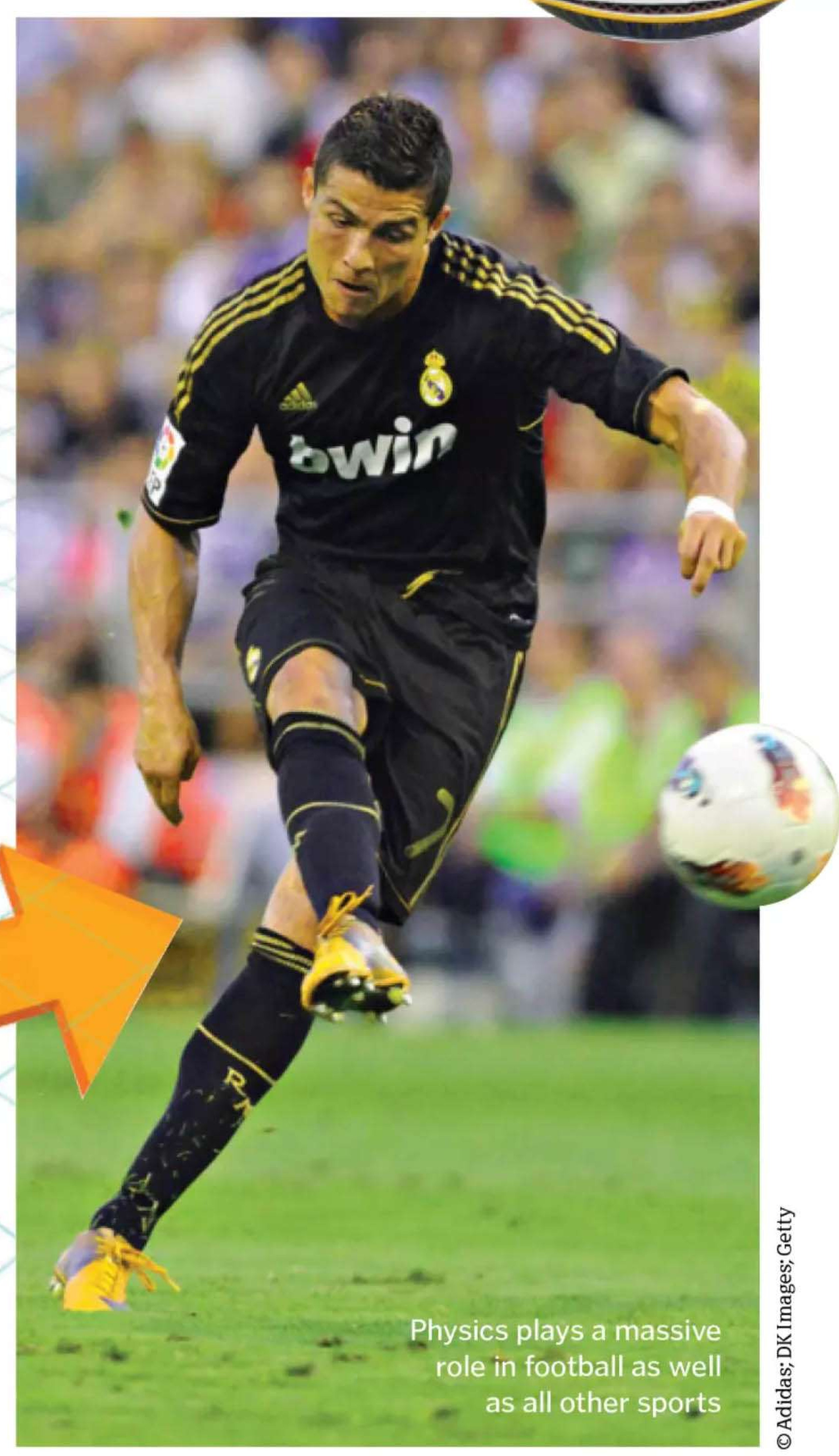
Guide to the curler

How a curling free kick plays out

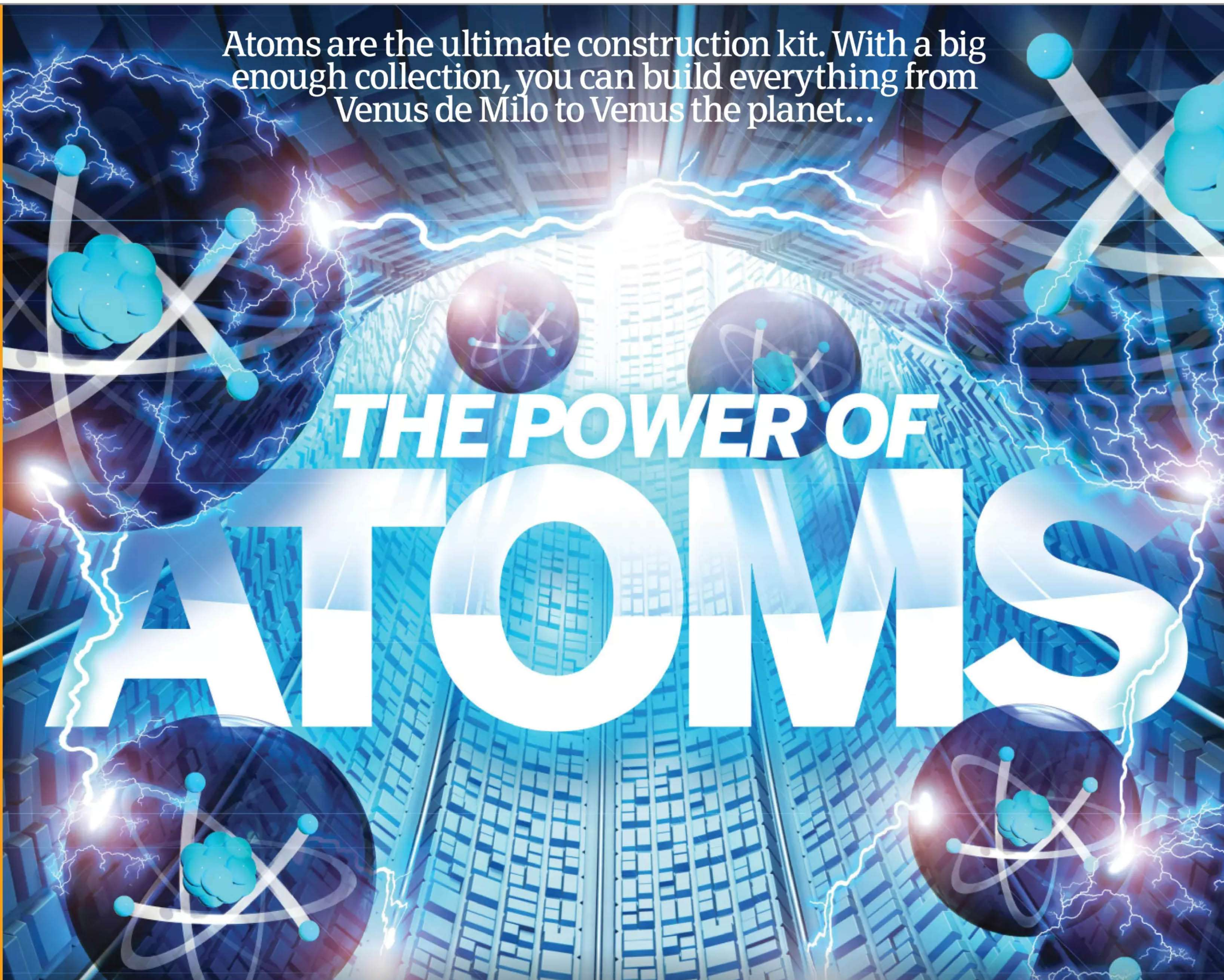




David Beckham made the art of the free kick one of his specialities



Physics plays a massive role in football as well as all other sports



THE POWER OF ATOMS

Atoms are the ultimate construction kit. With a big enough collection, you can build everything from Venus de Milo to Venus the planet…

Everything in the universe is made of countless tiny atoms that are joined into different structures, essentially like toy building blocks. But instead of snapping together through friction, like plastic blocks, atoms snap together through electrical charge.

At the centre of every atom you'll find the nucleus – a blob of positively charged particles called protons and neutrally charged particles called neutrons. The tiny nucleus is surrounded by even smaller negatively charged particles called electrons. Usually, there is an equal number of protons and electrons. Because of their opposite charge, these protons and electrons are attracted to each other, which is what holds the atom together. With this balance, the atom is electrically neutral.

But these electrons are a fickle bunch: they're not only attracted to their own atom's nucleus – they're sometimes attracted to the nuclei of other atoms as well. In the right situations, this cross-atom attraction can provide a sort of 'electron glue' that bonds multiple atoms together.

An atom's bonding prospects depend on its proton and electron count and arrangement, which is unique for every element on the periodic table. Electrons surround the nucleus at specific energy levels, called shells. The shell closest to the nucleus is the lowest energy level, and the shell farthest from the nucleus is the highest energy level. Each shell can hold a limited number of electrons. For example, the lowest-level shell holds a maximum of two electrons, and the next level holds up to eight electrons. To achieve maximum stability, electrons move to the lowest possible energy level that has available openings.

The critical factor in chemical bonding is the number of openings in an atom's outermost shell, called the valence shell. When there is the right combination of openings, electrons can jump from one atom to another, two atoms can share an electron, or many atoms can share a cloud of electrons. Atoms are more stable when their valence shells are full, so

5 TOP FACTS
ATOM TRIVIA

Super-dense
1 The nucleus which is located at the heart of every atom makes up more than 99.9 per cent of its mass, but only a trillionth of its total volume.

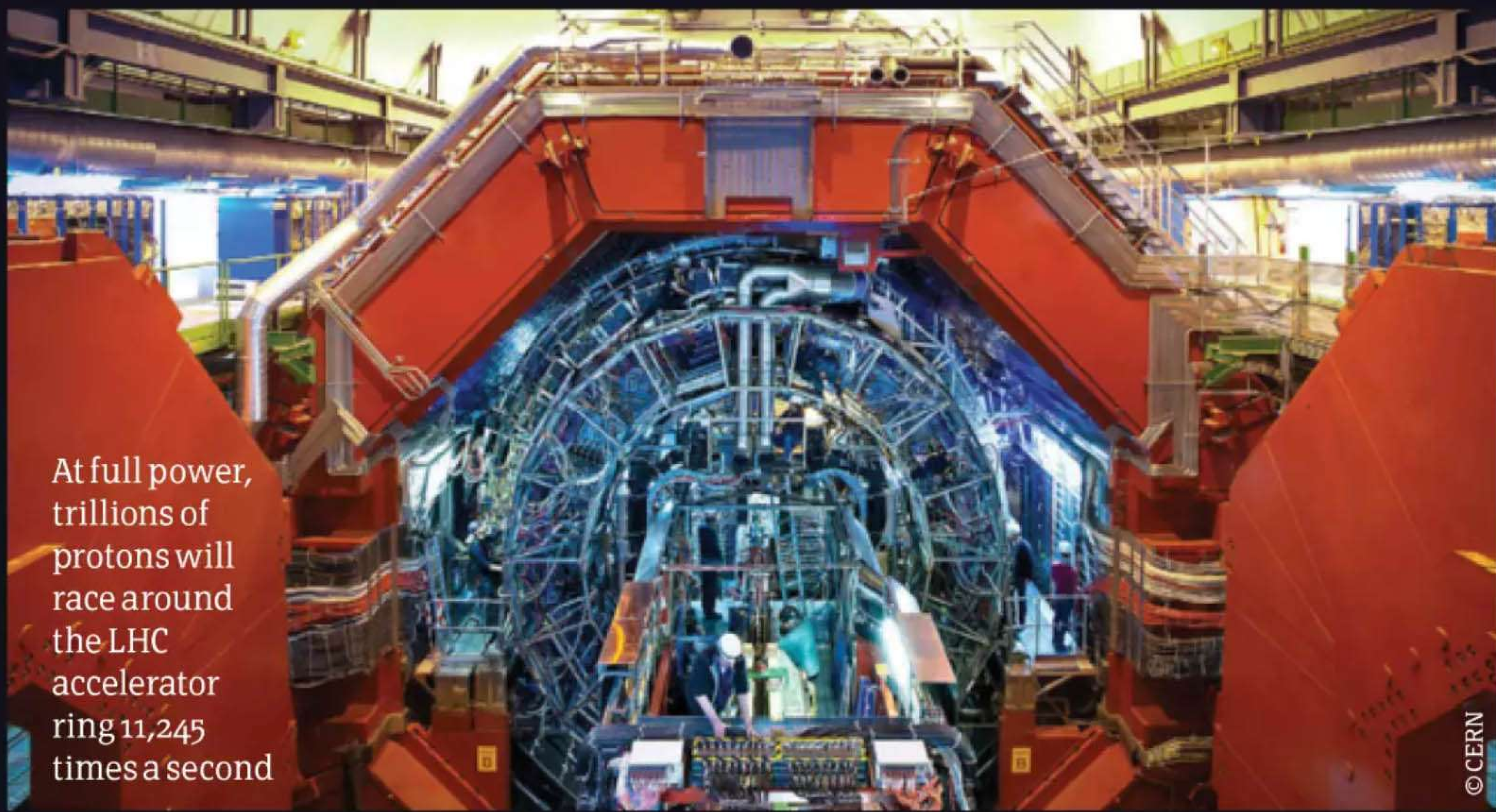
Electrons are tiny
2 At only 1/1,836th the size of a proton or neutron, electrons contribute almost nothing to an atom's mass, but are the most active component of an atom, responsible for bonding.

The rest is filler
3 More than 99.9 per cent of an atom's volume is empty space. If an atom's nucleus were the size of a basketball, its electrons would be zipping around several miles away.

The quantum leap
4 When electrons jump between energy levels, they don't move through the space between. Instead, they disappear from one level and then instantly reappear on another level.

The force is strong
5 Atomic nuclei are held together by the strong force, which is 10^{38} times stronger than gravity, but only operates on the minute scale of a nucleus.

DID YOU KNOW? As atoms circulate extensively over time, your body includes atoms that were once part of the dinosaurs


At full power, trillions of protons will race around the LHC accelerator ring 11,245 times a second

© CERN

electrons will readily move in ways that form complete valence shells.

When multiple atoms bond together, they form molecules. Molecules can consist of many identical atoms – that is, atoms of the same element – or they can include atoms of multiple elements. A multi-element molecule is called a compound. Collectively, vast numbers of molecules form the wide variety of materials that we know and love. The structure of the individual molecules, along with the way those molecules fit together, ultimately dictates how any material feels and behaves.

> "An atom's bonding prospects depend on its proton and electron count and arrangement, which is unique for every element on the periodic table"

Broadly speaking, there are three styles of organisation: gases, liquids and solids. In gases, molecules move about freely. In liquids, molecules fit together loosely, sliding over one another like marbles in a bowl. In solids, meanwhile, molecules are arranged in more rigid structures, and so don't move as freely.

Within these groups, different combinations and arrangements of atoms result in an incredible range of qualities and behaviours. Even limited to a set of identical atoms, structural changes can make huge differences. For example, compare diamonds and graphite. Both are arrangements of carbon atoms, but you don't see anyone proposing on bended knee with a pencil.

In a diamond, strong covalent bonds join atoms in a rigid lattice framework. The result is one of the hardest, toughest materials in the world. In graphite, on the other hand, carbon atoms are arranged in a layered structure, with very weak bonds between layers – so weak that touching a pencil to paper is enough to break them. The ability to combine and arrange atoms into different structures yields virtually unlimited possibilities. Scientists and engineers have already developed countless thousands of novel materials, and we're nowhere close to exhausting the potential combinations.

The chemical reactions involved in recombining atoms can prove useful themselves. For example, fire is the result of a chemical reaction between the chemical compounds in wood (or some other fuel) and oxygen in the atmosphere, triggered by intense heat. Burning wood produces char and gaseous compounds of hydrogen, carbon and oxygen. As the gases heat up, the compounds break apart, and the atoms recombine with oxygen in the air to produce water, carbon dioxide, carbon monoxide and nitrogen; this releases a great deal of energy in the form of heat and light in the process.

Between forming new materials and producing usable energy, the manipulation of atoms has always been at the heart of human technology – even when we had no clue atoms existed. In recent years, scientists have managed to make new atoms, forming 20 elements not observed in nature by combining existing nuclei into new super-heavy nuclei. These manmade atoms quickly fall apart, but stable variations may not be far off. In the 20th century, humans unlocked the internal energy of atomic nuclei for the first time, yielding both nuclear powerplants and bombs.

Today, physicists are investigating the even smaller components – quarks, leptons and bosons – that make up atoms. At this still mysterious level, new findings could fundamentally redefine our understanding of the universe.

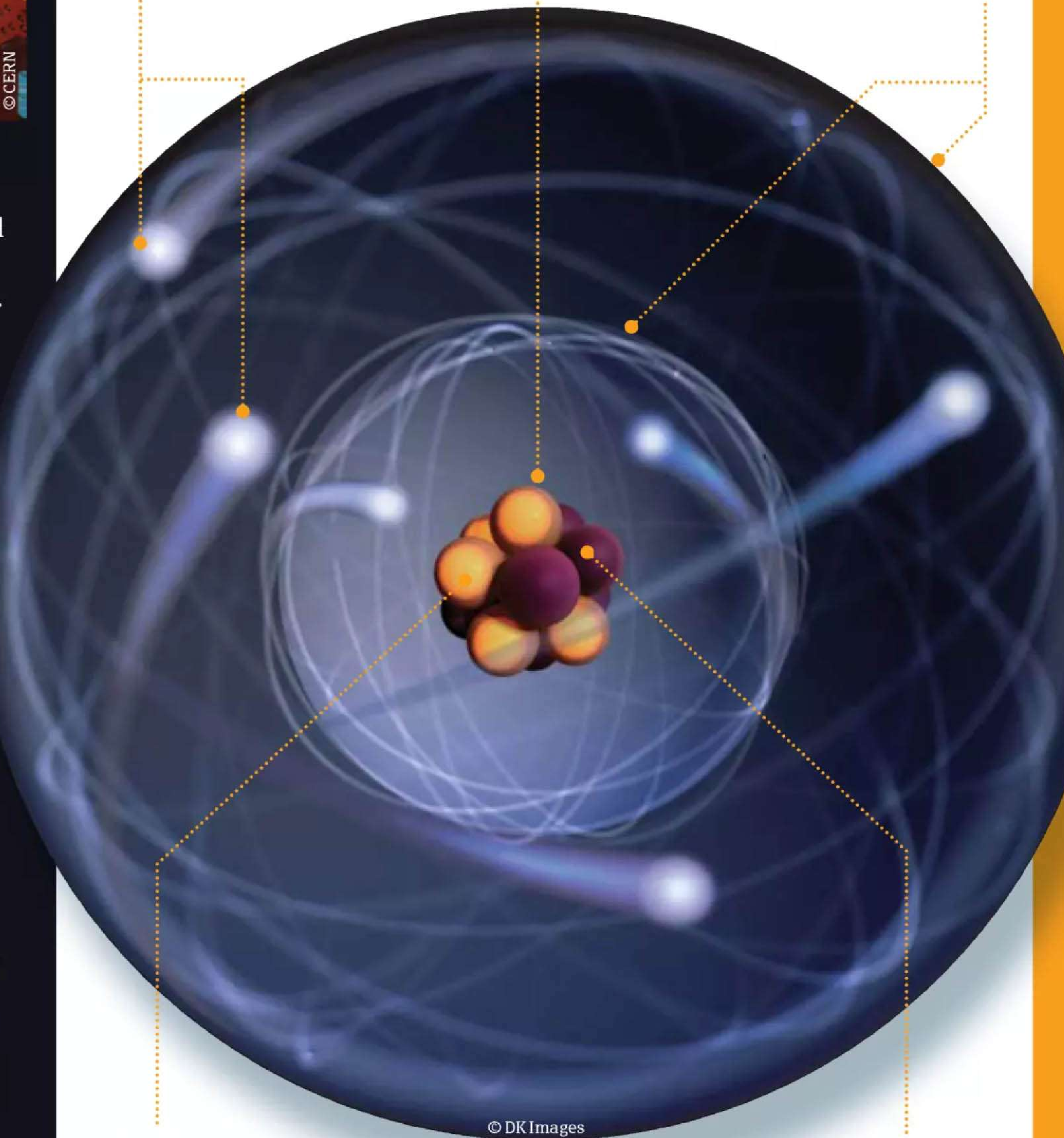
Anatomy of an atom

What are the fundamental parts that make an atom?

Shells
Electrons can only exist in set energy levels, commonly called shells. Each shell has openings for a limited number of electrons.

The nucleus
The centre of the atom, and almost all of its mass, is the nucleus. The nucleus is made up of protons and neutrons.

Electrons
Electrons are very small, negatively charged particles that move quickly around the atom's nucleus.


© DK Images

Protons
Protons are positively charged particles in the nucleus. All elements are defined by how many protons they have.

Neutrons
Neutrons – particles with no electrical charge – help give atoms their mass. They are slightly bigger than protons.


The 'Fat Man' nuclear bomb was dropped on Nagasaki, Japan, on 9 August 1945

Atomic models

Atoms don't follow the rules of Newtonian physics that we see every day in the world around us, making it impossible to visualise what's actually happening at an atomic level. The best that scientists can do is create theoretical models that give us a general conceptual comprehension of what's going on. Here are some of the noteworthy models that greatly advanced our atomic understanding...

Thomson's 'Plum Pudding' model (1904)

English physicist JJ Thomson discovered the electron as far back as 1897, showing for the first time that atoms had smaller constituent components. To account for the atom's overall neutral charge, Thomson theorised – in his 1904 model – that the negatively charged electrons must sit in a regular pattern within a uniformly distributed positive charge, like raisins in a plum pudding.

Rutherford's nuclear model (1911)

New Zealand-born physicist Ernest Rutherford, who studied at Cambridge University, disproved Thomson's model, when he demonstrated the existence of a positively charged atomic nucleus. Rutherford proposed the atom was like a miniature solar system, with a relatively massive, Sun-like nucleus at the centre, orbited by much smaller planet-like electrons.

Bohr's shell model (1913)

In classical mechanics, any charged particle moving in a curved path emits radiation. Consequently, in Rutherford's model, electrons would lose energy and collapse into the nucleus. Danish physicist Niels Bohr proposed electrons moved in a different type of orbit. He theorised electrons surrounded a nucleus in fixed energy levels (shells) and only emitted radiation when they 'jumped' from shell to shell.

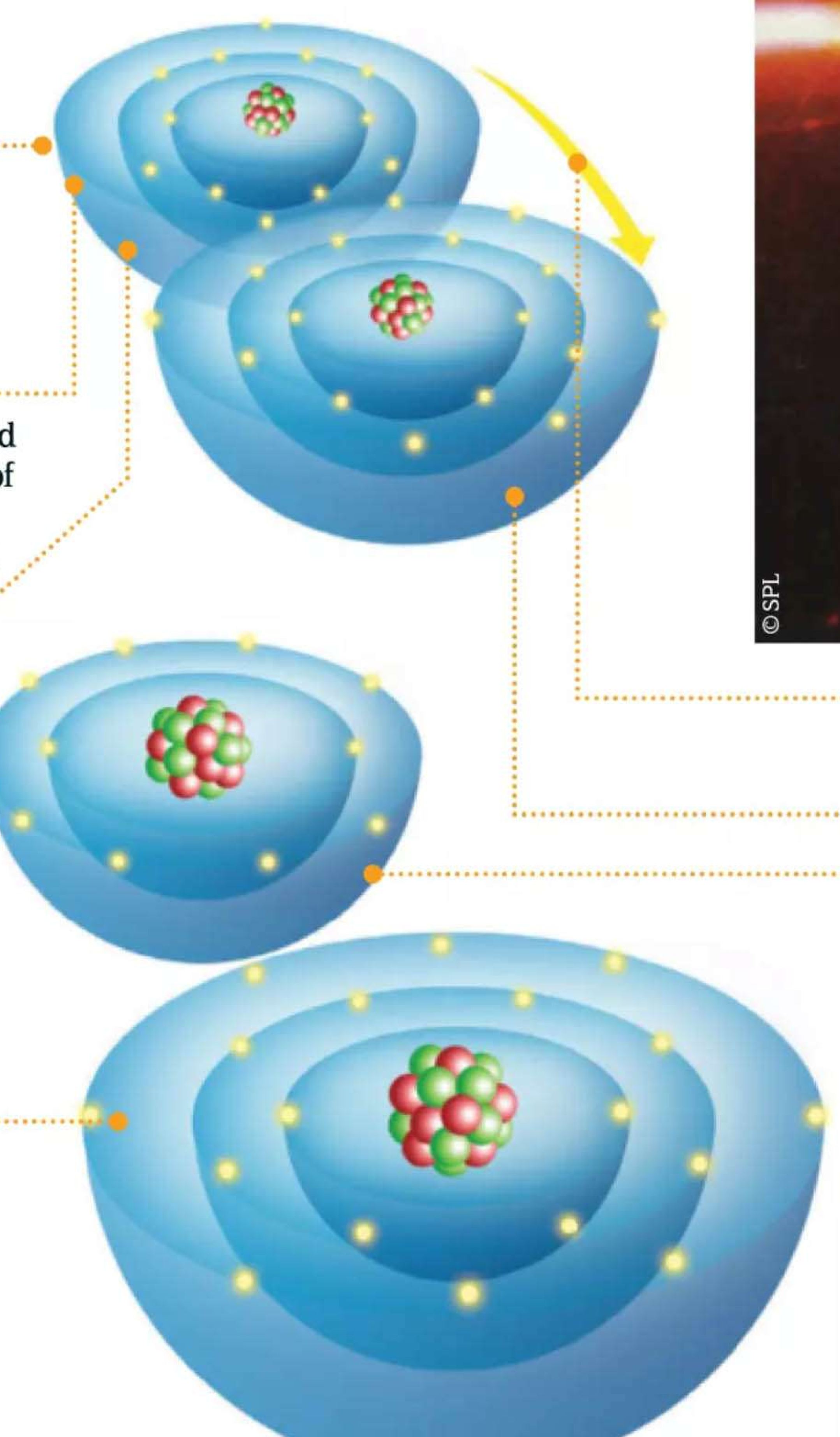
What are elements and compounds?

Elements are substances made entirely of one type of atom. Each element is defined by how many protons are in a single atom of that element. For example, every hydrogen atom has just one proton, while every gold atom has 79 protons, and so on. In the right circumstances, atoms of different elements can join together to form a chemical compound. The bonds that hold compounds together result from various movements of electrons. Here are two examples:

Bombarding atoms together leads to the dislodging of subatomic particles

© SPL

Ionic bond



Ionic bond
Ionic bonds form when an electron jumps from one atom to another, resulting in two electrically charged atoms, called ions.

Valence shell
Electrons travel in set energy levels called shells. Each shell has a limited number of openings for electrons. The number of openings in the outermost level, known as the valence shell, determines how an atom can form bonds.

Electron leap
To achieve overall stability, the spare electron from the sodium atom leaps to fill the chlorine atom's valence shell.

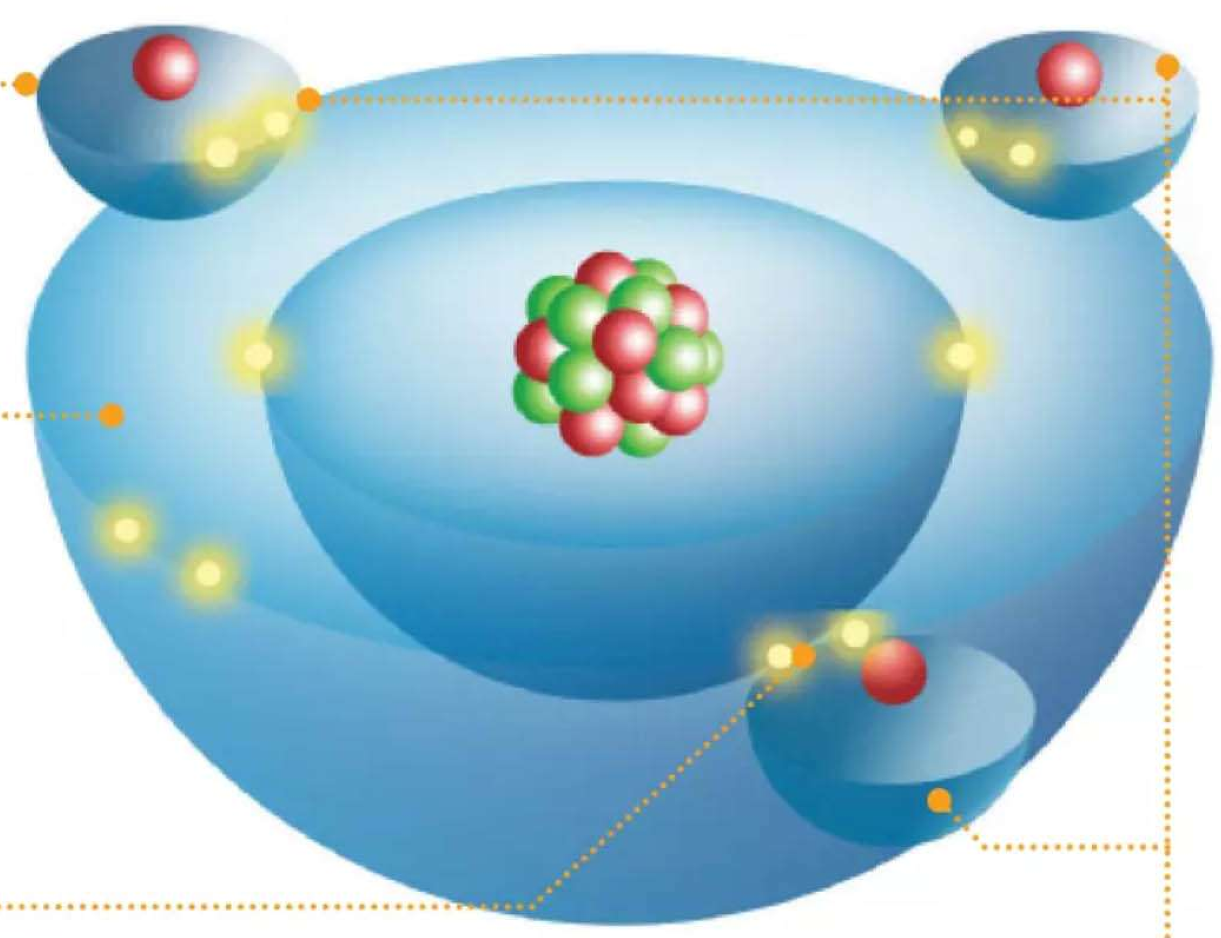
Sodium atom
The sodium atom's valence shell has only one electron, leaving seven openings.

Chlorine atom
A chlorine atom's valence shell holds seven electrons, leaving only one opening.

Chlorine anion
The chlorine atom now has 18 electrons and 17 protons, making it an anion – an atom with a net negative charge. The opposite charges bond the two atoms together to form the compound sodium chloride, more commonly known as table salt.

Sodium cation
The sodium atom now has ten electrons and 11 protons, making it a cation – an atom with a net positive charge.

Covalent bond



Covalent bond
Atoms can also form compounds by sharing electrons between them, in covalent bonds.

Nitrogen atom
A nitrogen atom has five electrons in its valence shell, leaving three openings.

Electron pairs
Each of the three hydrogen atoms shares its original single electron and one of the original nitrogen electrons, collectively forming the compound ammonia.

Hydrogen atoms
Each of these three hydrogen atoms has a single electron in its valence shell, leaving one opening.

From stars to space dust, everything in the universe is made up of atoms

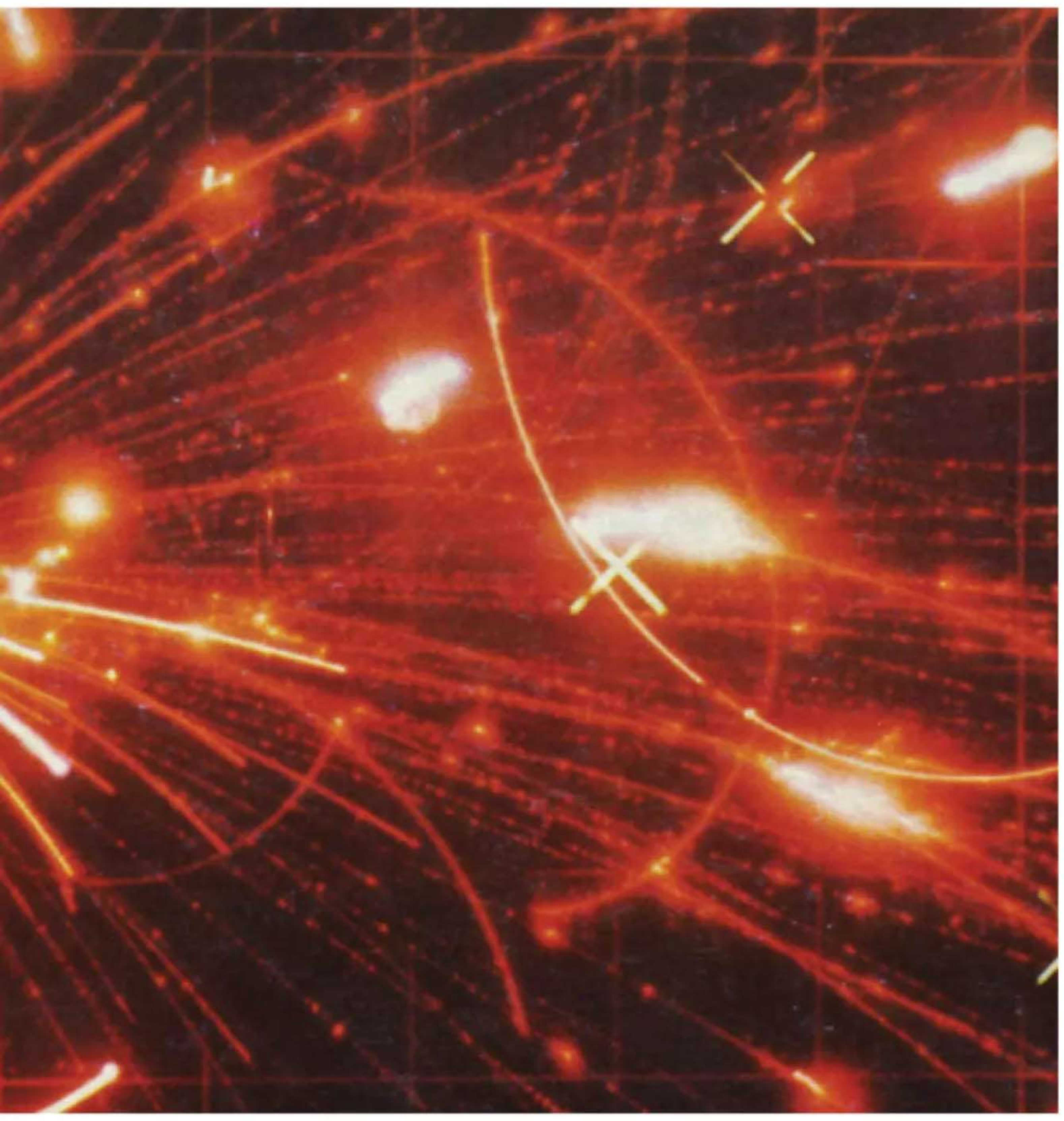
AGE (OF UNIVERSE) 13.7bn yrs

EST LIFE SPAN OF STABLE ATOM 10^{35}> years

EST LIFE SPAN OF MOST UNSTABLE MANMADE ATOM 7 milliseconds

ELECTRON SPEED 2.2mn m/s

DID YOU KNOW? *If you took all the empty space in the human race's bodily atoms, the matter could fit between your fingers*



Radioactive decay explained

Most atoms are highly stable, meaning that the nucleus will always hold together, barring extreme circumstances. But in some atoms, the energy that binds the nucleus will eventually fail in a process called radioactive decay – the spontaneous disintegration of the nucleus.

The most notorious unstable atoms are elements with a very high number of protons, such as uranium (92 protons). But some lighter elements, such as carbon, are radioactive as well, when they have too many or too few neutrons. Neutron-count variations are called isotopes. For example, while garden-variety carbon-12 (six protons and six neutrons) is entirely stable, carbon-14 (six protons and eight neutrons) is radioactive.

© NASA

Radioactive decay results in the ejection of subatomic particles from the nucleus. In alpha radiation, the atom ejects two protons and two neutrons. In beta radiation, a neutron turns into a proton, ejecting a neutrino particle and a free electron, called a beta wave. In gamma radiation, the nucleus releases extra energy in the form of a photon. Energy from the ejected particles can mutate human DNA, sometimes resulting in disastrous cellular changes, ie cancer.

The nucleus material that's left forms a 'daughter atom'. When the proton count has changed, the daughter atom will be entirely different from the original atom. Carbon-14 decays into nitrogen, for example.

How to split an atom

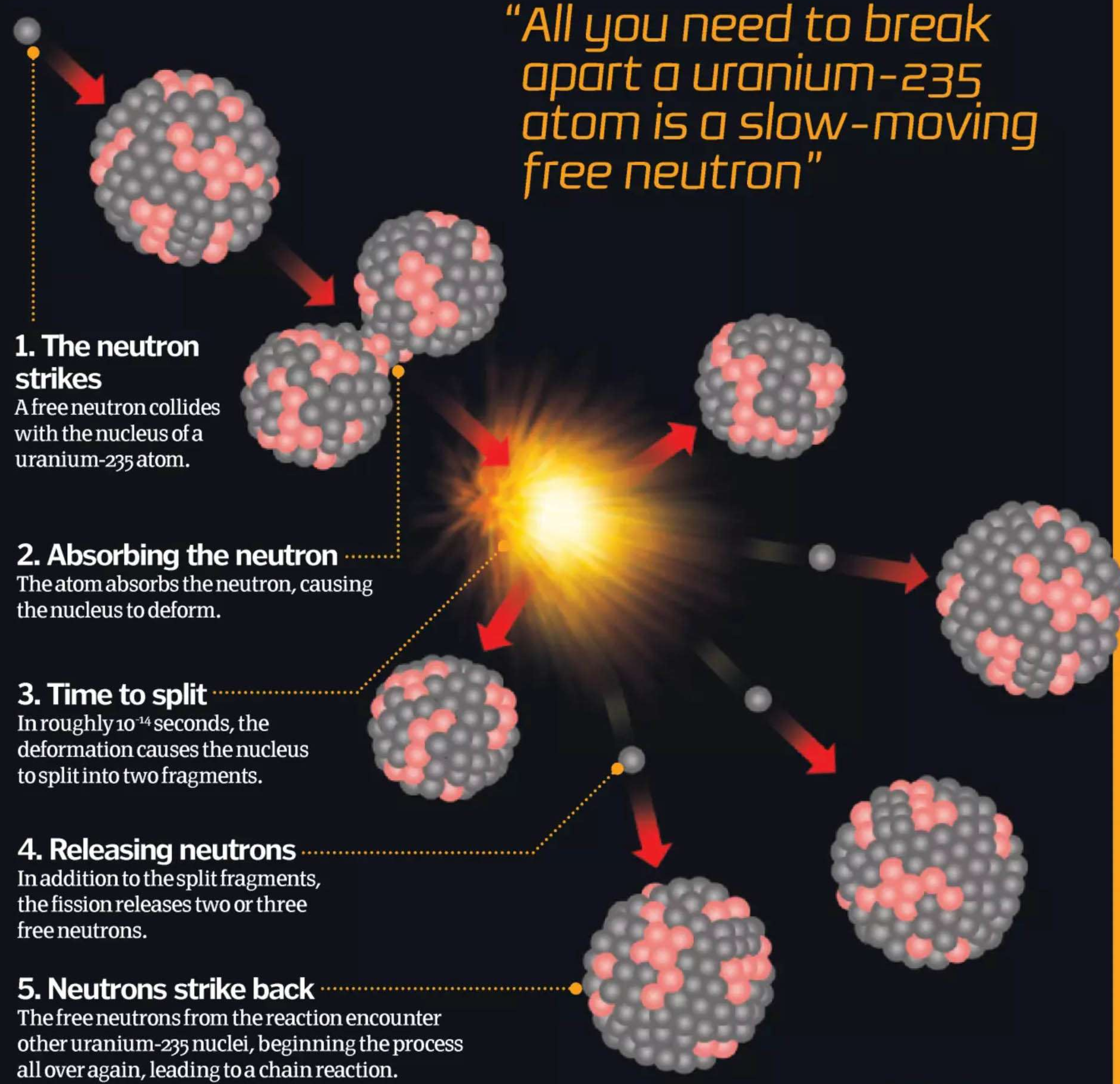
Add this to the pile of mind-bending atom qualities: an atomic nucleus has less mass as a whole than its protons and neutrons would have separately. How is this possible? Well, when the nucleus is formed, some of the mass of its constituent parts changes into energy that binds the protons and neutrons together. In other words, there's high potential energy locked up in the nucleus.

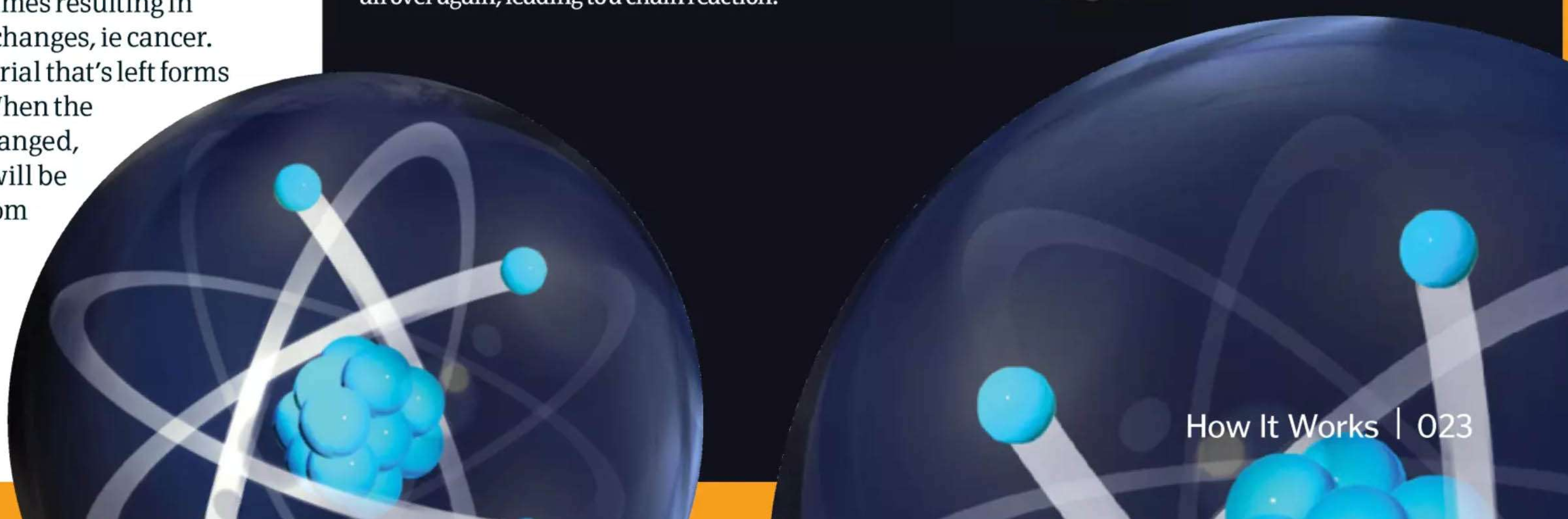
It's possible to release this energy, and actually harness it, by splitting specific types of atoms apart into multiple fragments – a process known as nuclear fission. All you need to break apart a uranium-235 atom is a slow-moving free neutron. The uranium atom will absorb the free neutron, the extra energy makes the uranium nucleus highly unstable, and the atom splits into two smaller atoms and two or three free neutrons. The potential energy in the nucleus is released as kinetic energy, in the form of these particles moving at great speed. The resulting free neutrons, in turn, can break apart other uranium-235 atoms, leading to a chain reaction.

A powerplant controls the reaction and harnesses the heat of this kinetic energy in order to generate steam that turns turbines. In contrast, in an atomic bomb the reaction is allowed to go unchecked, in order to generate a massive explosion.

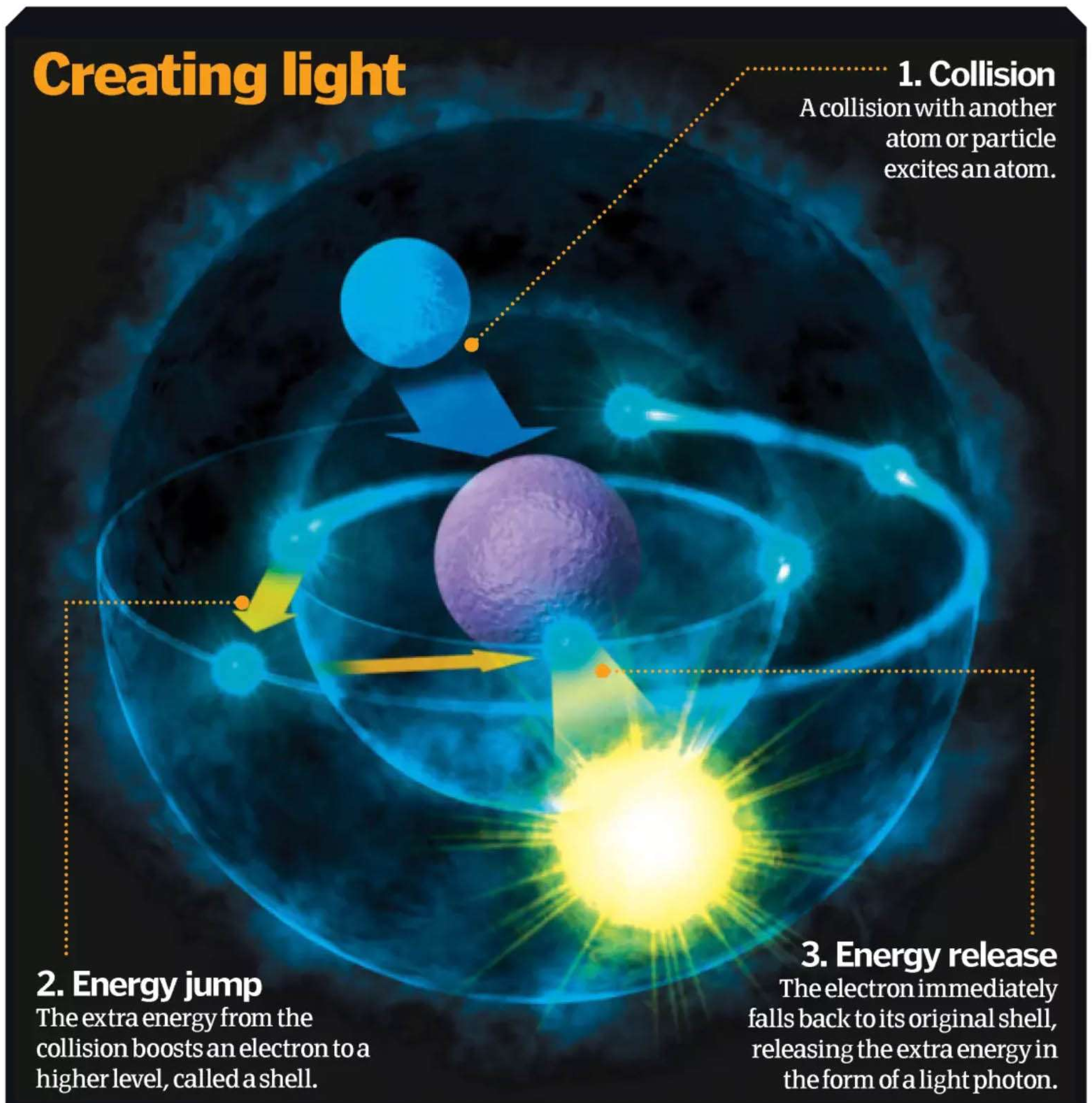
You can also tap into this energy through nuclear fusion – the combining of two nuclei into a new nucleus. Nuclear fusion generates the energy of stars and hydrogen bombs. However, nobody has been able to harness it effectively as a power source yet.

"All you need to break apart a uranium-235 atom is a slow-moving free neutron"





"13.5 per cent of the world's electricity in 2010 came from the world's 436 nuclear reactors"



How atoms emit light

Light is the result of electrons moving between defined energy levels in an atom, called shells. When something excites an atom, such as a collision with another atom or a chemical electron, an electron may absorb the energy, boosting it up to a higher-level shell. The boost is short-lived, however, and the electron immediately falls back down to the lower level, emitting its extra energy in the form of an electromagnetic energy packet called a photon. The wavelength of the photon depends on the distance of the electron's fall. Some wavelengths, such as radio waves, are invisible. Photons with wavelengths in the visible spectrum form all the colours that we can see.

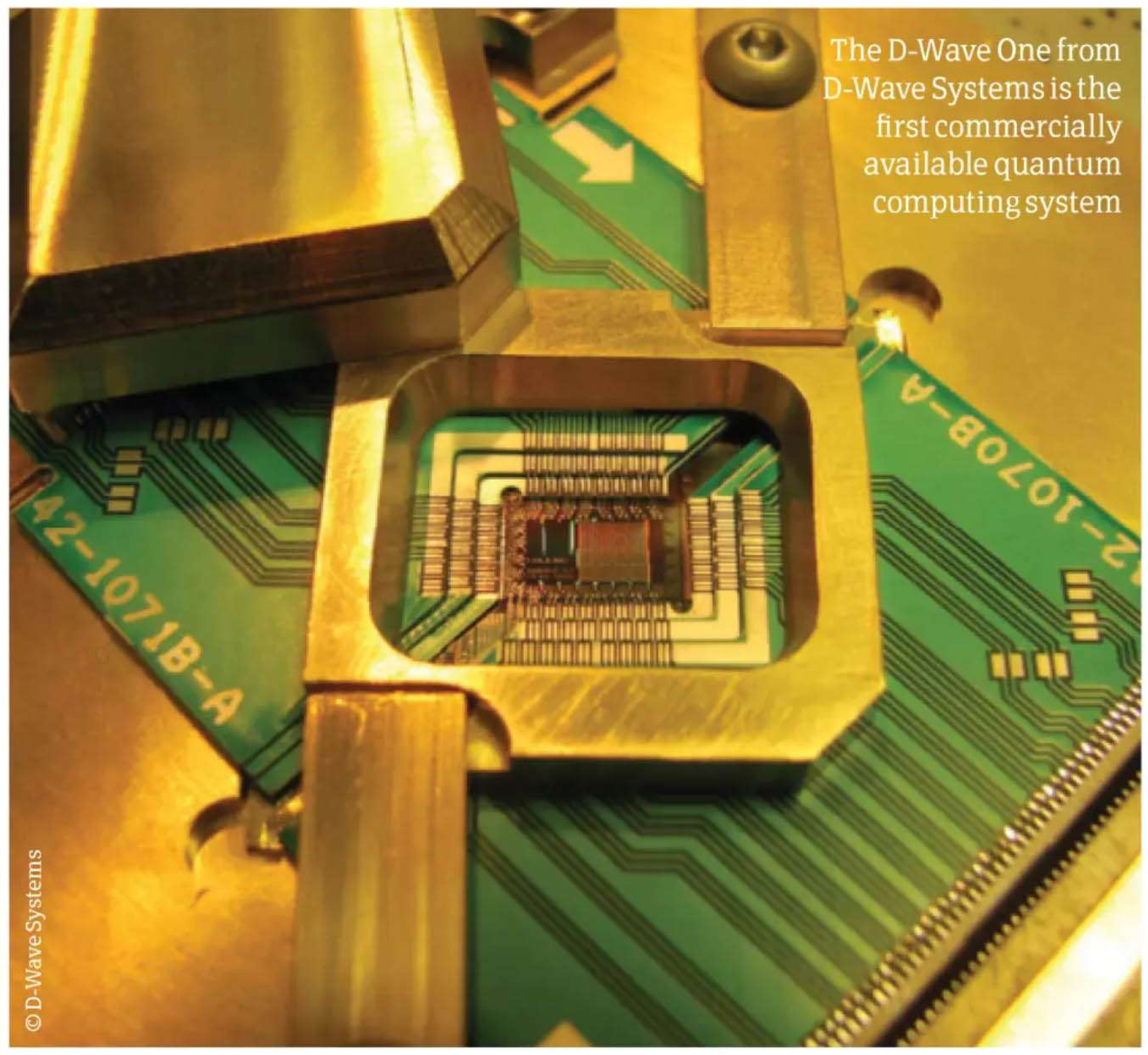

France is currently leading the way with nuclear power, with nearly 80 per cent of its overall energy derived from atom power

Atoms and quantum computing

One of the many oddities about activity on the subatomic level is that subatomic particles do not have a defined state until they are observed. Instead of saying exactly where a proton, electron or other subatomic particle actually is, physicists instead talk about a probability cloud, indicating all of its possible states.

The weird but real phenomenon of quantum tunnelling helps illustrate this. As a subatomic particle approaches a barrier, one edge of the probability cloud for its position moves to the other side of the barrier. So, there's a small chance it actually will be on the other side of the barrier. Sometimes, it is on the other side, effectively tunnelling straight through the barrier.

Another way to define this ambiguity is to say a subatomic particle is in all possible positions at once. Contrast this with a computer bit, which at any moment, has a value of either 1 or 0. The fundamental idea of quantum computing is to employ each of the many 'superposed' states to perform part of a calculation, in order to do the entire calculation far more quickly than a conventional computer could manage. The field is now in its infancy, with limited implementations, but it could revolutionise computing in the foreseeable future.



The D-Wave One from D-Wave Systems is the first commercially available quantum computing system

Atom power by the numbers

No matter how you feel about nuclear power, it's part of your life. According to the Nuclear Energy Institute, 13.5 per cent of the world's electricity production in 2010 came from the world's 436 nuclear reactors. France leads the pack, drawing 77.7 per cent of its power from nuclear energy in 2011. The UK comes in at considerably less at 15.7 per cent.

Other energy sources still exceed nuclear power. The International Energy Agency lists coal/peat as the top source, providing 40.6 per cent of the world's power. Natural gas is second with 21.4 per cent, followed by hydropower with 16.2 per cent. Solar, wind, biofuels, heat and geothermal power combined amount to only 3.3 per cent.

430 BCE — Philosopher Democritus states if you keep cutting matter up, you'll eventually get an invisible piece (called an atomos).

1704 CE — Sir Isaac Newton (right) theorises all matter is made of hard, unbreakable but movable particles.

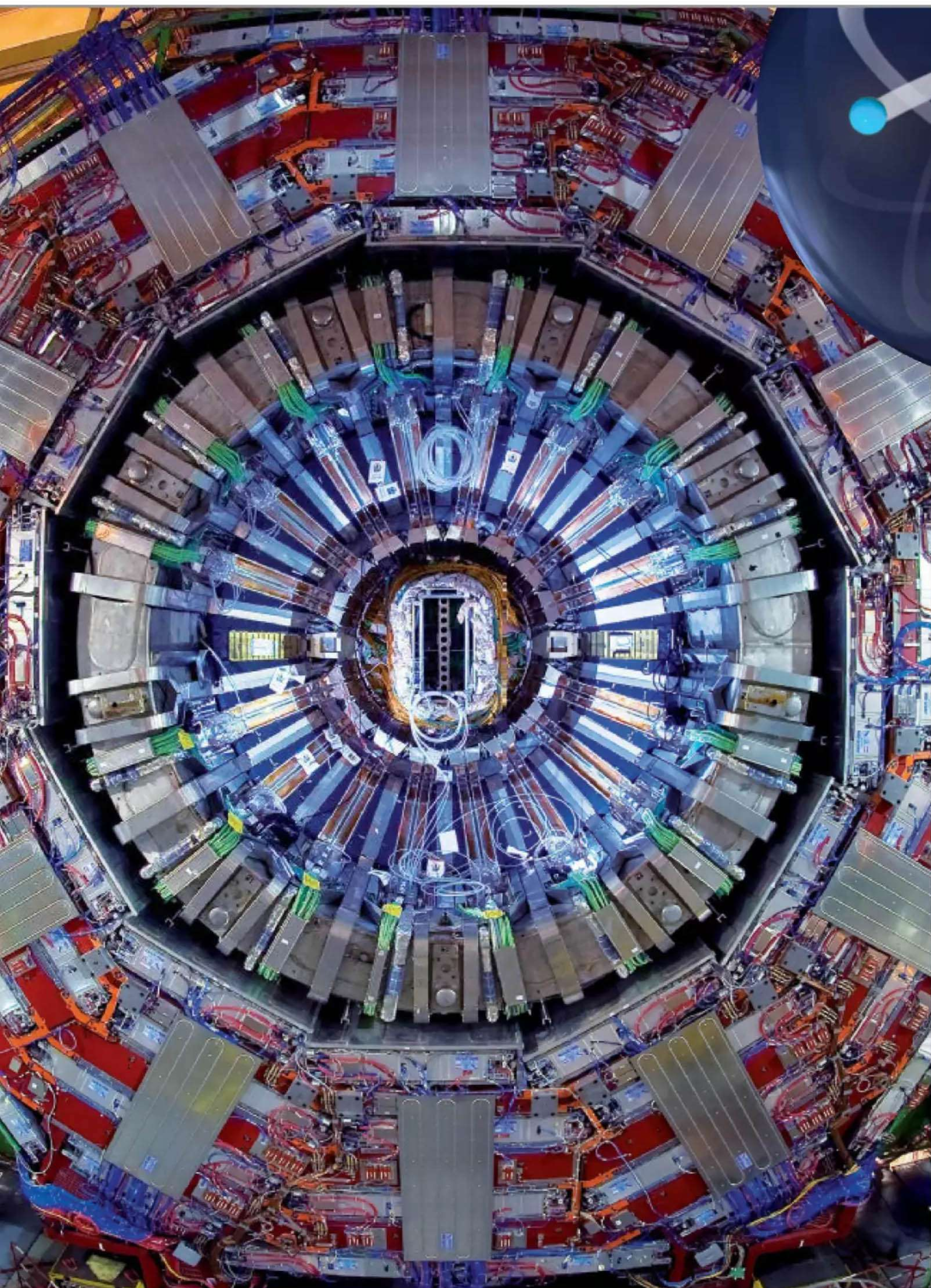
1803 — John Dalton proposes each element has its own atom, and describes chemical reactions as a rearrangement of atoms.

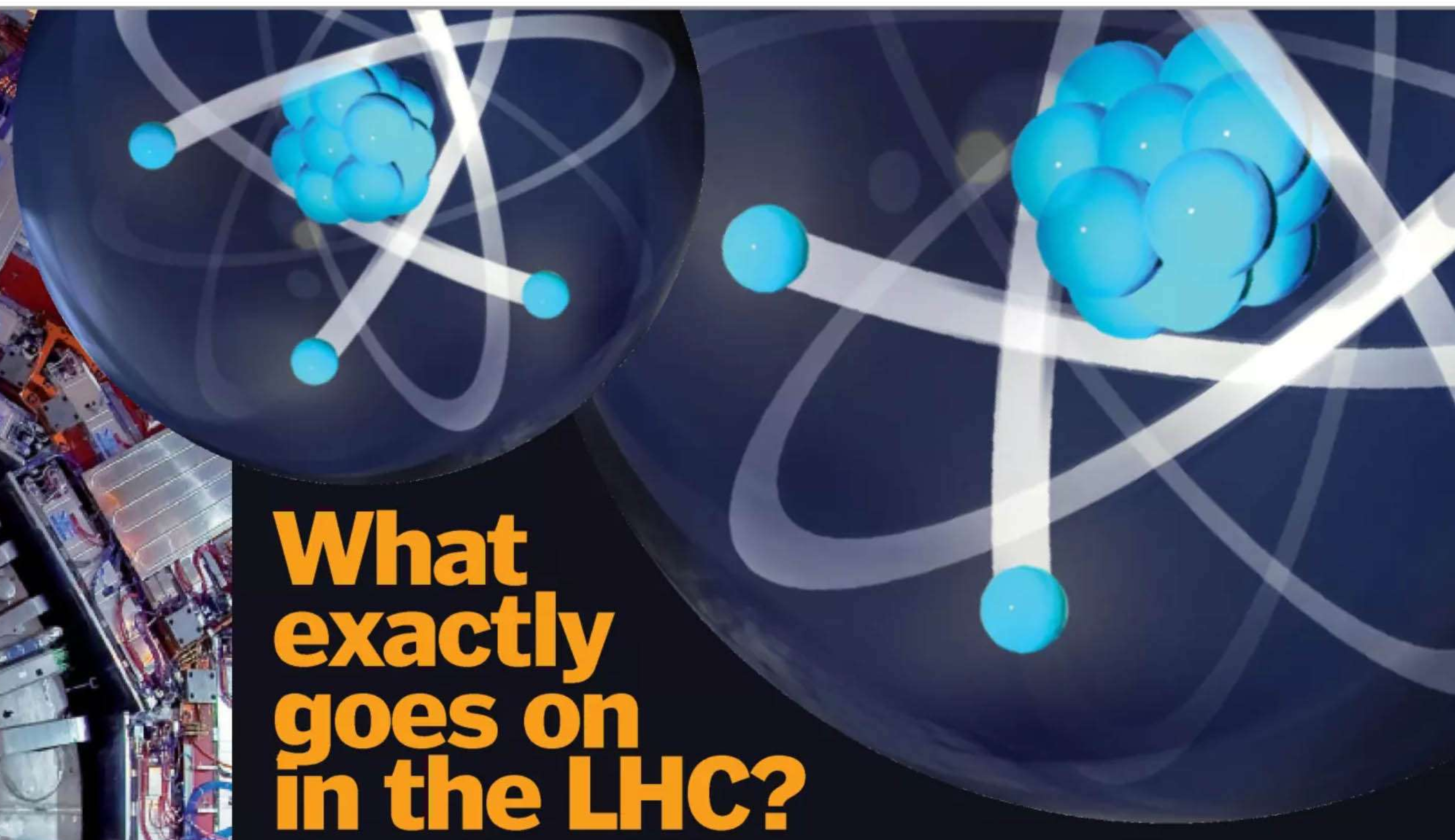
1869 — Dmitri Mendeleev organises elements on the periodic table, which shows patterns of chemical reactions.

1897 — JJ Thomson discovers the electron, before going on to propose the Plum Pudding theory.

1922 — Niels Bohr wins the Nobel Prize for Physics for his work on atoms, much of which applies to this day.

DID YOU KNOW? *When two subatomic particles meet, quantum entanglement links them to some extent forever*



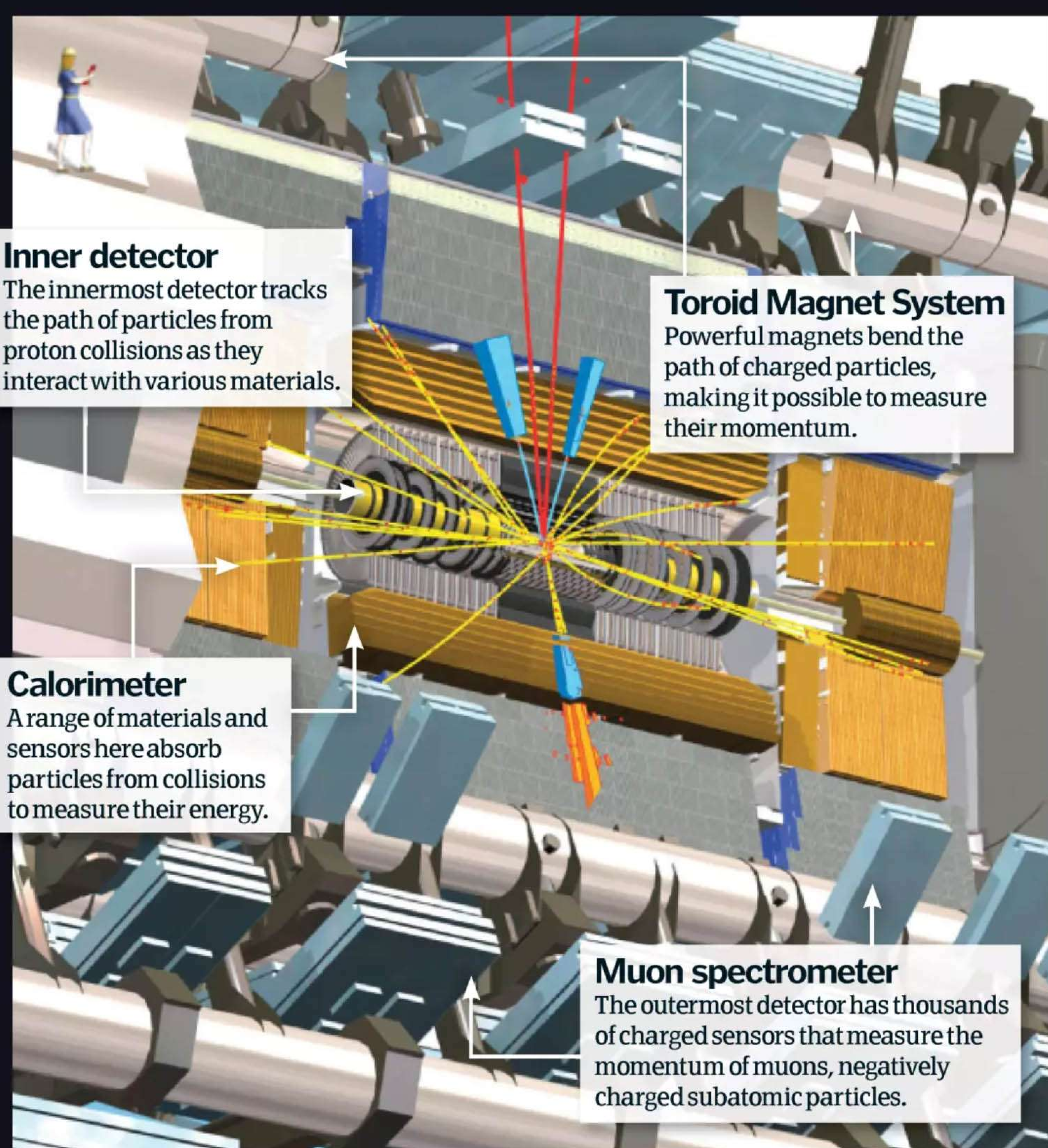


What exactly goes on in the LHC?

Some 50-170 metres (165-560 feet) beneath Switzerland and France, you'll find the Large Hadron Collider, a 27-kilometre (17-mile) circular racing track for atoms and subatomic particles. The collider accelerates and crashes streams of these particles into each other at 99.9999991 per cent the speed of light, in order to break them apart. So, why bother? Well, it takes collisions of this unprecedented intensity to get a look at some of the infinitesimally small particles that make up atoms. Examining these pieces is as close as physicists can get to seeing what the universe was like immediately after the Big Bang.

Researchers at the European Organisation for Nuclear Research (CERN) are collecting data on the speed, mass, energy, position, charge and trajectory of the particles in each collision. Analysis of the data could lead to new understandings of the nature of mass, gravity, dark matter and even other dimensions.

Inside the ATLAS detector



What is the Higgs boson?


Professor Peter Higgs proposed his boson theory back in 1964

The Higgs boson is a theoretical particle proposed by British physicist Peter Higgs as part of the Standard Model of particles and forces. The Standard Model is an incomplete theory that describes how the 12 known fundamental particles and three of the four known forces in the universe fit together (it doesn't account for gravity).

According to this theory, many fundamental particles had no mass immediately following the Big Bang, but gained mass later from interacting with an invisible energy field called the Higgs field, by way of a particle called the Higgs boson.

The Higgs boson is one of several missing pieces that make the Standard Model incomplete. Finding it with the Large Hadron Collider would lend additional credence to the Standard Model, giving us a strong indication of the nature of matter. Not finding it, after extensive searching, would indicate this theory is wrong, spurring physicists to focus on other schools of thought.

"The tension rapidly transforms this tiny hole into a big tear, ripping the balloon apart with an almighty bang"

The shockwaves created by a bursting balloon are made visible in this high-speed photo by adding talcum powder

DID YOU KNOW? Helium molecules slip through the tiny gaps in stretched latex; that's why helium balloons are usually made of foil

Balloon-popping science

Find out why the properties of latex give bursting balloons their bang

Balloons are made of latex, a special type of polymer called an elastomer. If you were to look at latex under a powerful microscope you would see a tangle of long molecules resembling a plate of cooked spaghetti. Each molecule is linked to its neighbours by bonds called cross-links, forming a dense network. When pulled apart, these tangled molecules straighten out, but as soon as the tension is released they snap back to their original shape, lending latex its stretchy quality.

Inflate a balloon and the latex molecules stretch out, putting the balloon's skin under a large amount of tension. If you then jab the balloon with a needle, you create a tiny fault in the latex. The existing tension rapidly transforms this tiny hole into a big tear, ripping the balloon apart with an almighty bang.

Don't feel embarrassed if popping balloons make you jump – their deafening noise is caused by nothing less than a sonic boom. As the balloon tears, the resulting pieces of latex contract at great speed. The ends of each piece move so fast that they break the speed of sound in latex, sending a shock wave travelling through the material.

Sharp objects aside, any process that creates a weak point somewhere on the balloon makes it liable to pop, from a naked flame to a tiny spark caused by static electricity discharging. Latex also becomes weaker and stiffer over time, allowing faults to develop gradually. This explains why balloons sometimes seem to mysteriously burst of their own accord.

No bang theory

It might seem illogical but there is a way to pierce a balloon without it popping – discover how in this step-by-step...

1. Inflate the balloon
For this trick, use a good-quality, medium-sized balloon. Take a deep breath and inflate the balloon to full size – stretching the latex a little beforehand makes this easier. Then let out about a third of the air and tie a knot.

2. Prepare a skewer
Take a wooden skewer, making sure to pick a sharp one with no splinters which could tear the balloon. Dip the tip of the skewer in vegetable oil, which will act as a lubricant to reduce friction and help the point glide through the balloon's skin.

3. Pierce the balloon
Start at the bottom (beside the knot) as this is where the balloon's polymer molecules are stretched the least. Carefully push the skewer into the balloon where the rubber looks darkest. Gentle pressure will help, but don't jab yourself!

4. Out the other side
Gently push the skewer through the balloon, guiding it toward the opposite end. The latex here is also under less tension than elsewhere, so it can be pierced without bursting the balloon. Push the skewer until it emerges through the skin again.

5. Take a bow
Job done – although you should expect the trick to take a few attempts before you get it right. You can now remove the skewer from the balloon if you wish – it still won't pop at this stage but the air inside the balloon will leak out fairly fast.

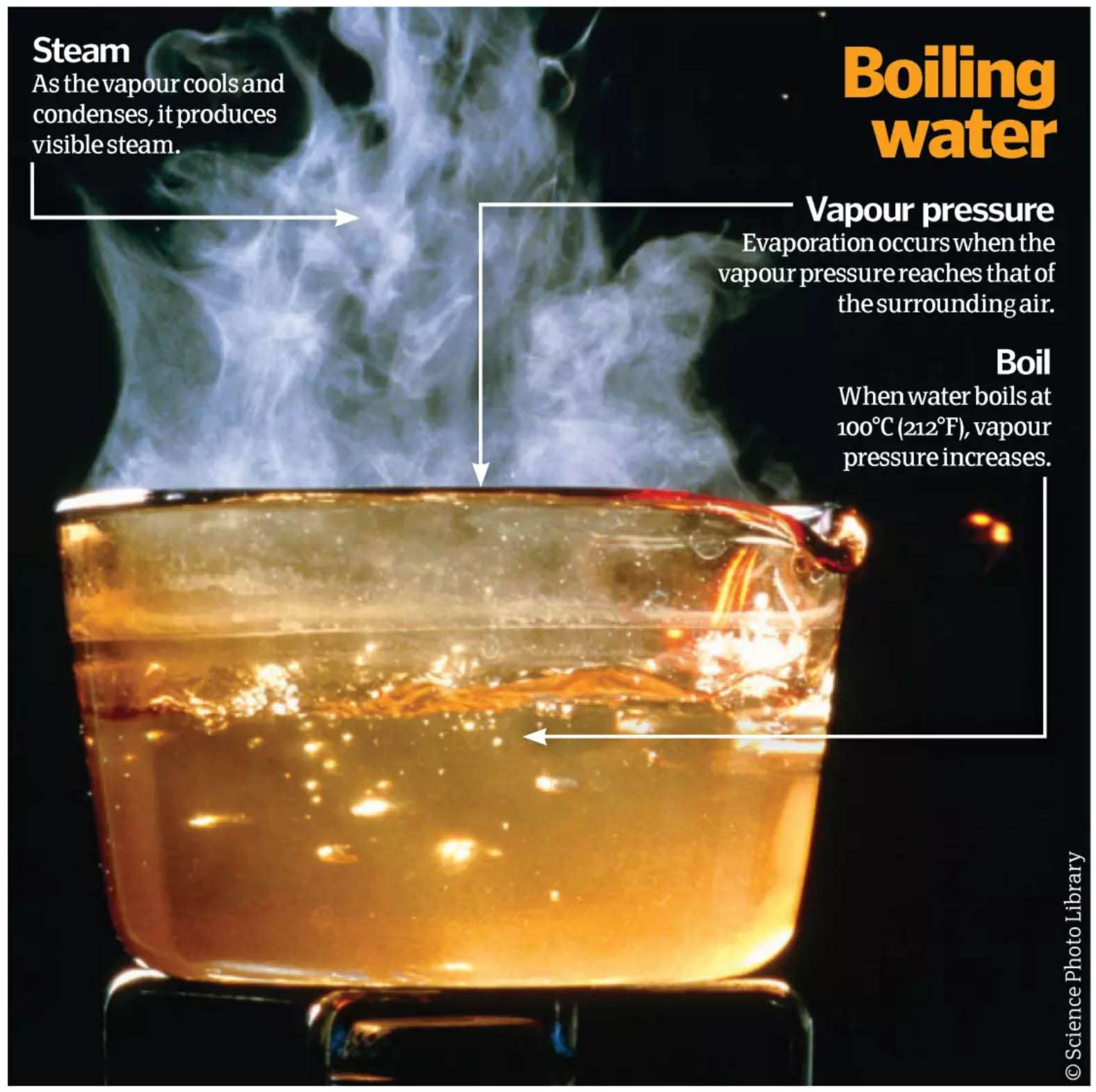
"There is a difference between evaporation of vapour and steam"

Evaporation and steam

How do these processes work, and is there a difference between them?

The change of state from a solid or a liquid to a vapour is known as 'evaporation'. This change of state occurs from the amount of energy the molecules have. Apart from at absolute zero (-273.15 °C), when molecules are said to have zero energy, molecules are in constant motion and, as temperature increases, they gain more and more energy. This in turn increases their movement and, the faster they move, the more likely they are to collide with one another. When these collisions occur, a molecule can gain enough energy – and subsequently heat – to rise up into the atmosphere, because as we know hot air rises.

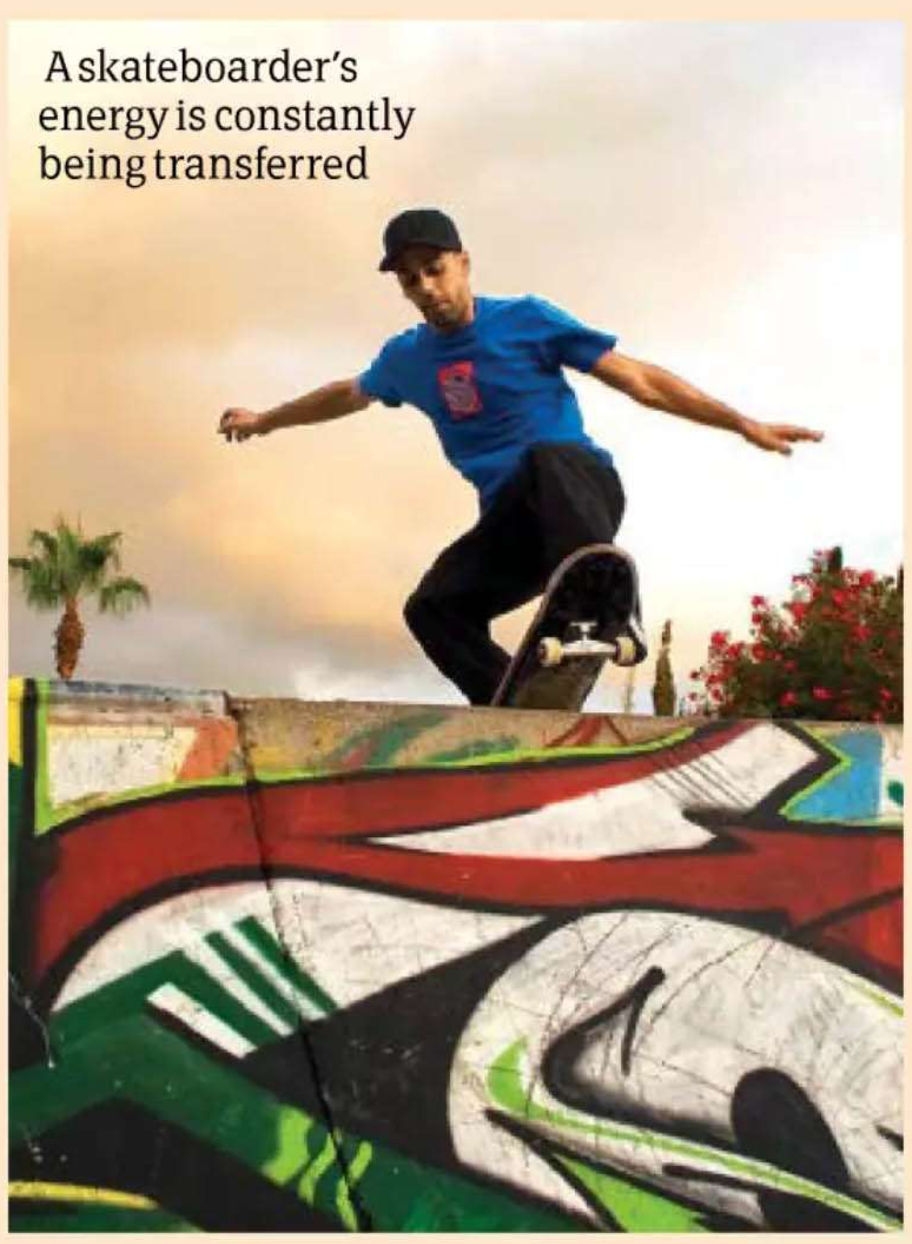
However, there is a difference between evaporation of vapour and steam. While vapour can be said to be any substance in a gaseous state at the same temperature as its environment, steam is specifically vapour from water that is hotter than the surrounding environment, commonly seen when boiling. There is no difference in chemical composition of the two. The steam we actually observe is the vapour cooling and condensing as it leaves the hot water and enters the cooler surrounding air.

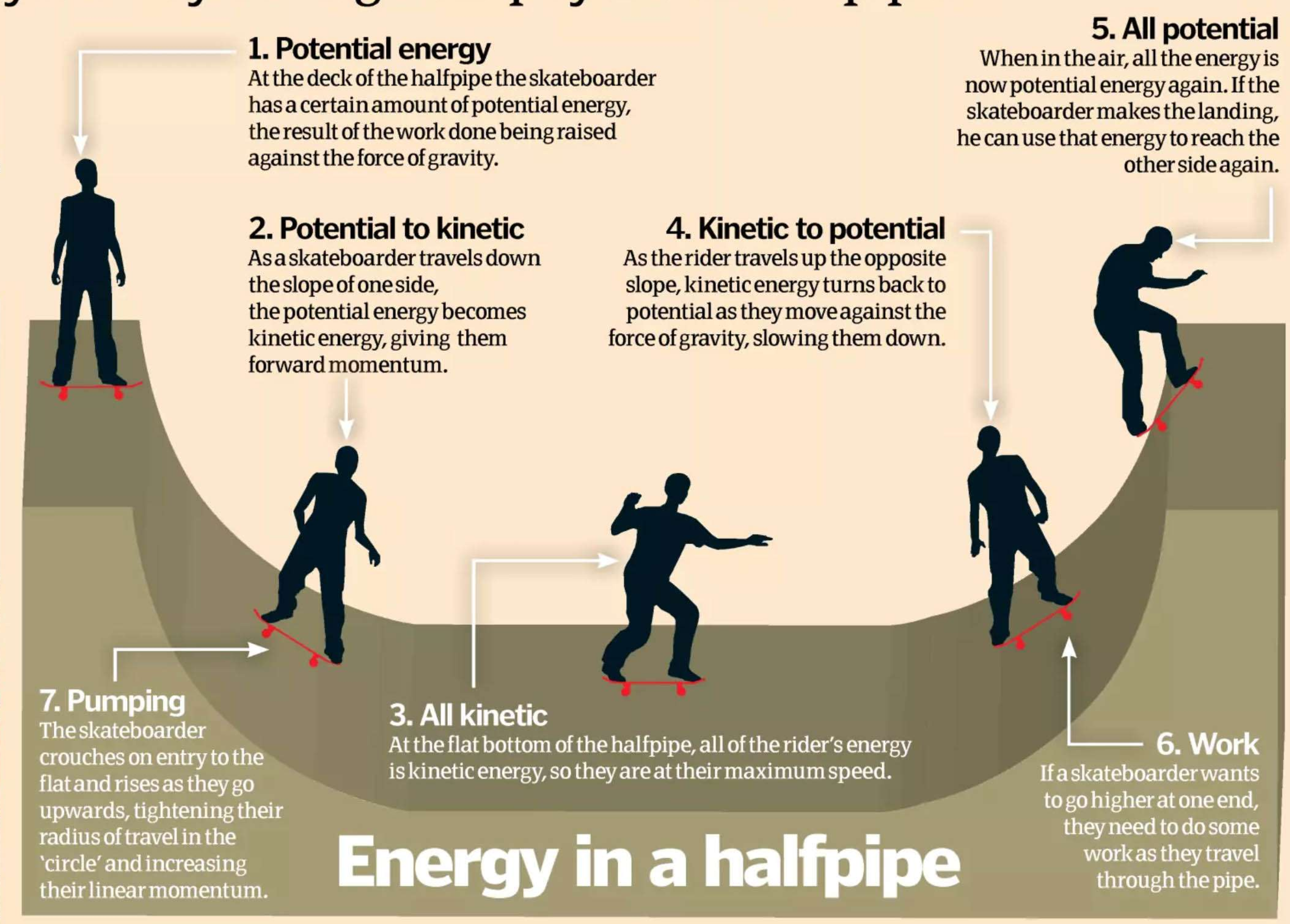


The science of skateboarding

Kick, twist and grab your way through the physics of half pipes

In a halfpipe a skateboarder will typically start at one end (deck), then roll down into the flat of the halfpipe. They carry enough speed and momentum to shoot up the other side, gaining 'air' to perform tricks before landing again in the bowl of the halfpipe.


A skateboarder's energy is constantly being transferred



KEY DATES
HISTORY OF TIME

1500 BCE Ancient Egyptians divided night-time into 12 parts and daytime into 10, with two hours for dawn and dusk.

1283 The first weight-driven clock was created in England; it sounded a bell to indicate time, hence the Celtic name 'clocca'.

1300s The hours of the day were standardised, divided into two 12-hour periods and measured beginning at midnight.

1656 The pendulum clock, developed by Christiaan Huygens, was the first to show seconds on its face.

1949 The first atomic clock was built in the USA, allowing extremely accurate timekeeping.

DID YOU KNOW? *Quantum clocks use aluminium and magnesium ions and are even more precise than optical lattice clocks*

Redefining the second

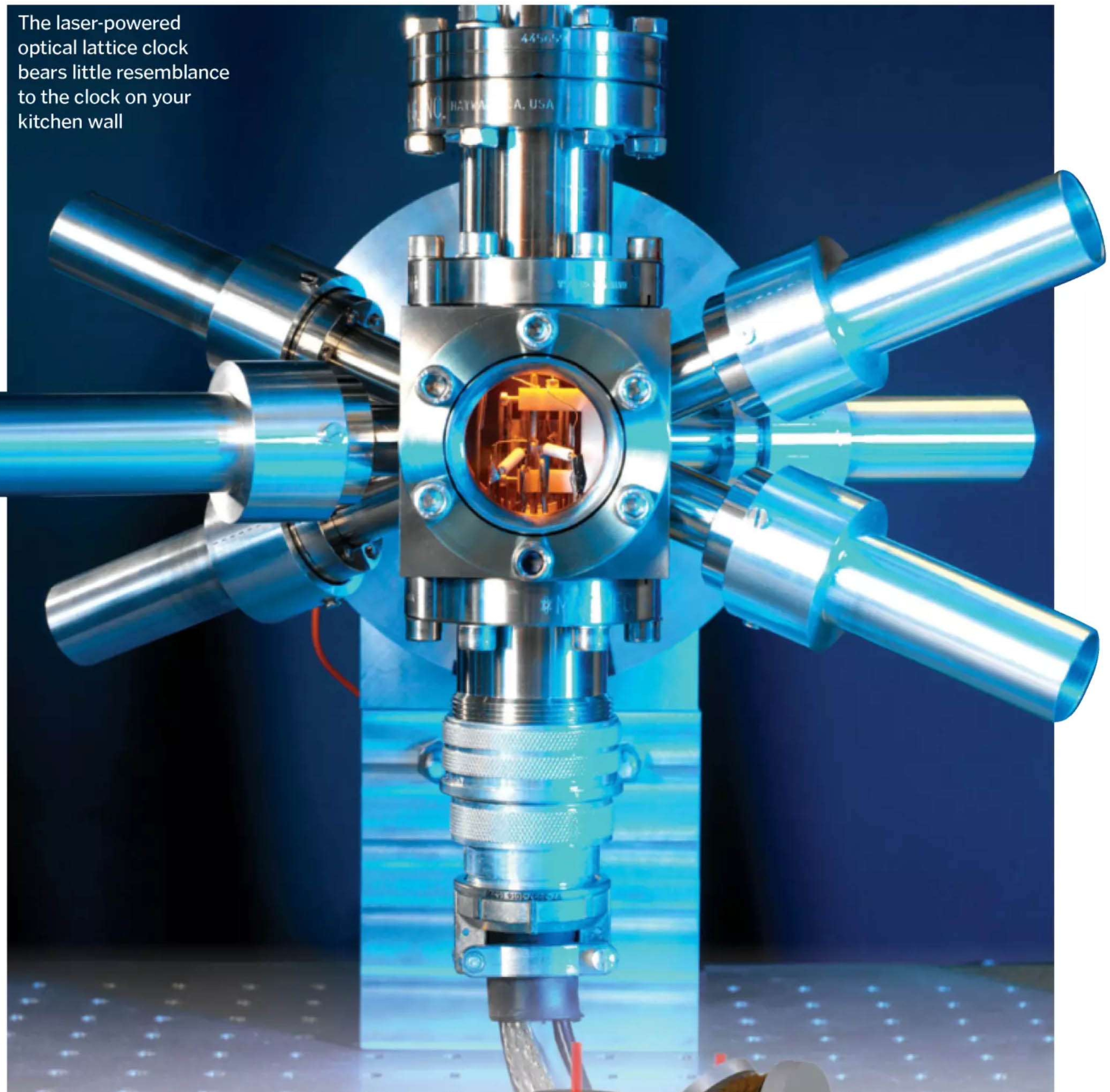
How do laser-powered optical lattice clocks measure time so precisely?

A grandfather clock uses a pendulum to keep time – a swinging weight that oscillates back and forth at fixed intervals. However, if the pendulum swings once every second, a tiny error quickly spirals into a major timekeeping problem. The solution is to break the second down even further and to use a 'pendulum' that swings much faster.

Atomic clocks, developed in the Fifties, are based on this principle. Instead of a swinging pendulum, these devices use the oscillations of caesium atoms as they jump between energy states when exposed to microwave radiation. In a single second, a caesium atom oscillates an incredible 9,192,631,770 times.

Optical lattice clocks take this idea one step further still. Instead of exciting atoms with microwaves, laser beams are used. These oscillate much more rapidly, splitting the second into even more fragments, and thus enabling more precise measurement.

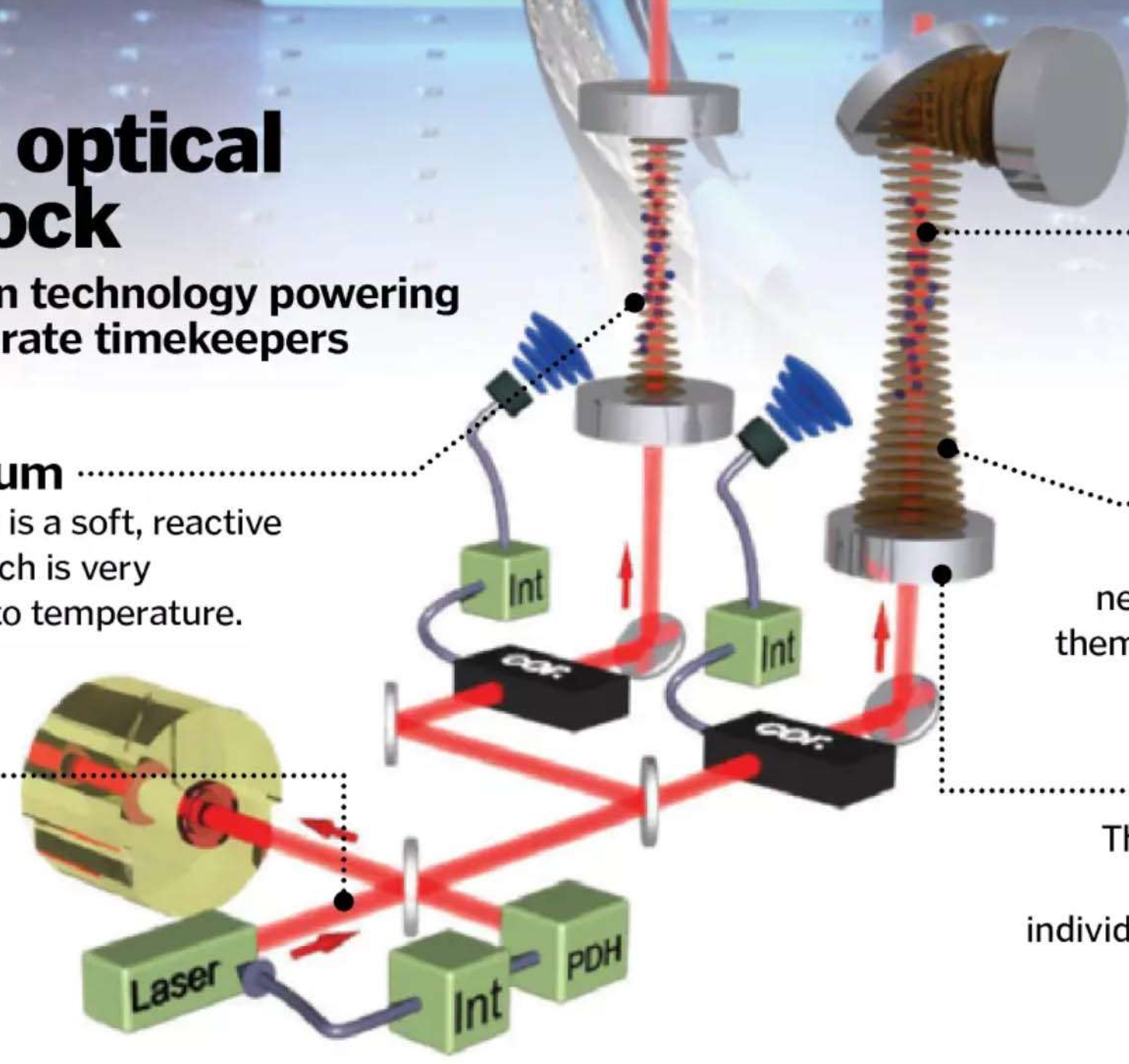
Strontium atoms are cooled by lasers until they move no faster than a few centimetres every second. The laser beam creates a pattern similar in shape to an egg box, which traps the individual atoms in a regular lattice, allowing their atomic 'tick' to be measured.



The laser-powered optical lattice clock bears little resemblance to the clock on your kitchen wall

Inside an optical lattice clock

A look at the main technology powering these super-accurate timekeepers



Strontium Strontium is a soft, reactive metal which is very sensitive to temperature.

Laser Laser beams are used to manipulate the strontium atoms, trapping them in a lattice, causing them to oscillate (vibrate).

Stability Up to 10,000 cooled atoms are used to keep time, making the clock highly stable.

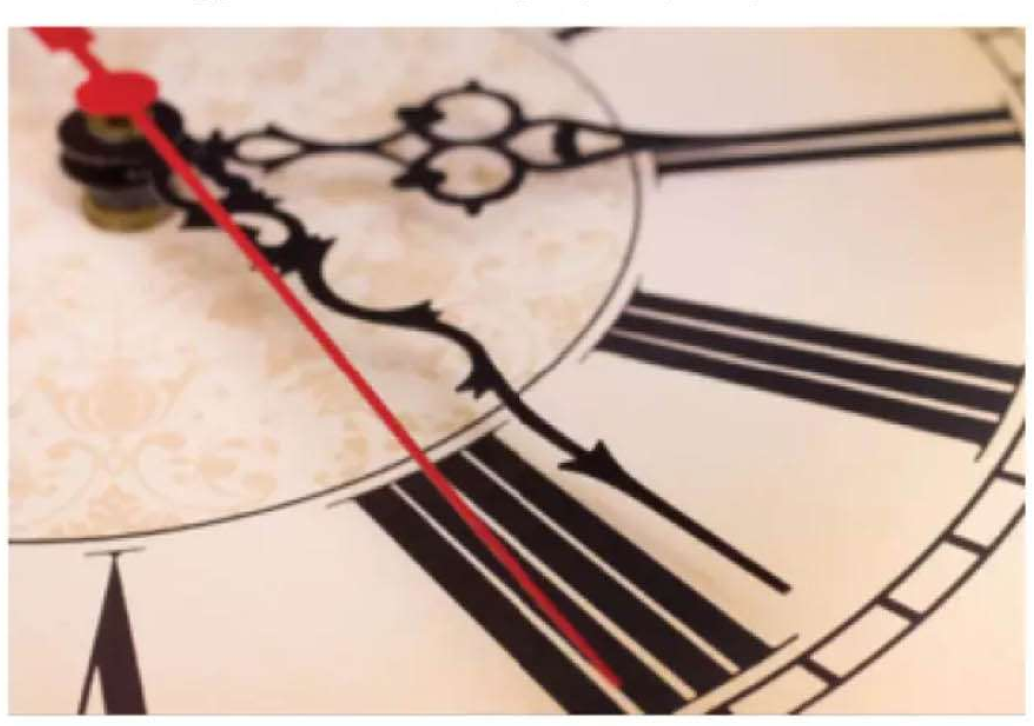
Absolute zero The atoms are cooled to near-absolute zero, slowing them down so the oscillations can be measured.

Optical lattice The laser beam produces a standing wave, trapping individual atoms in the pockets.

Second nature

From 1000 CE and right up until the Sixties, a second was defined, much as you might expect, as 1/86,400 of the average solar day – ie 60 seconds in every minute, 60 minutes in every hour, 24 hours in every day. However, given that the Earth wobbles on its axis and our orbit around the Sun is not consistent, a more accurate means of measuring time was required.

The atomic clock enabled us to measure time much more precisely, defining one second as the time it takes a caesium atom to cycle between two energy states exactly 9,192,631,770 times.



> "The sheet has set frequencies at which it will naturally resonate as the sound waves travel through it"

Seeing sound

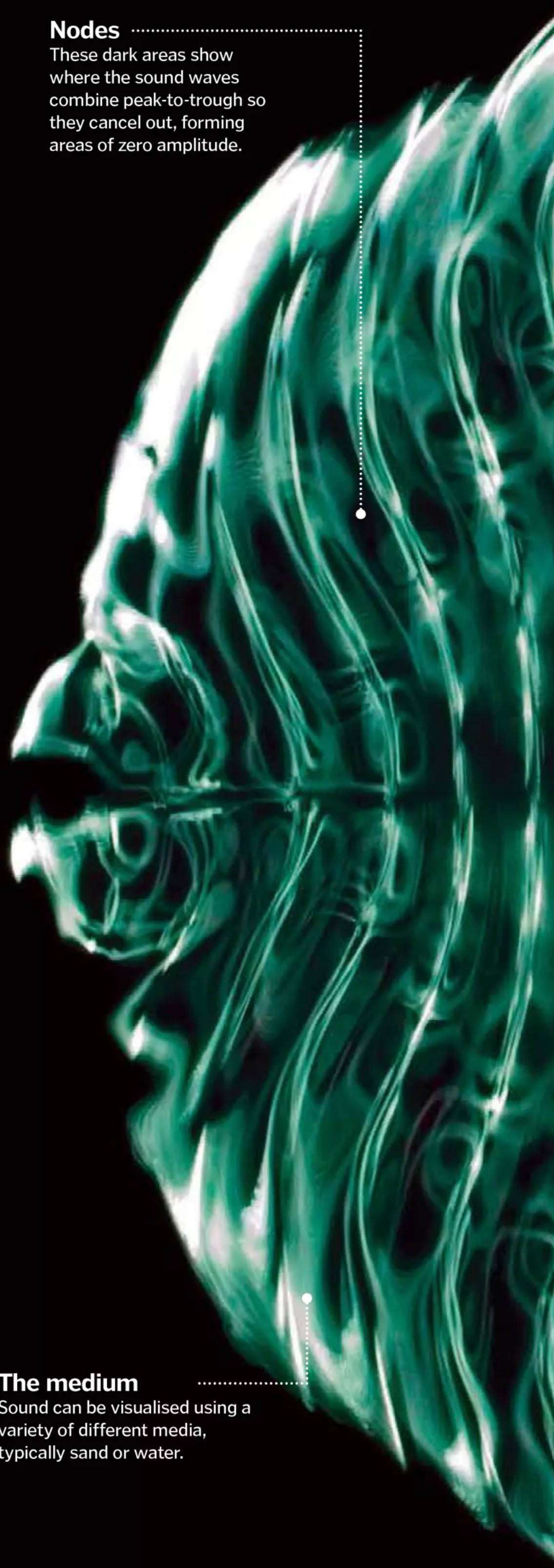
Discover the science of cymatics, which enables us to observe the behaviour of sound waves

The incredible geometric patterns on this page may look artificial, but they are, in fact, the visualisation of how sound waves interact as they travel across a surface. The study of these figures is called cymatics, which derives from the Greek word 'kima' (wave) and was first coined by Swiss scientist Hans Jenny in 1967, but the phenomena had been observed for hundreds of years by the likes of Da Vinci and Galileo.

The patterns are best observed using thin sheets of either metal or glass, known as a Chladni plate after its inventor (see the 'Ernst Chladni' boxout), connected to a signal generator which can oscillate at a variety of audio frequencies. The sheet has set frequencies at which it will naturally resonate as the generated sound waves travel through it. This creates a patchwork of areas where the waves either combine destructively (ie peak meets trough) to cancel each other out, or constructively (ie peak meets peak) forming a larger wave. These sections are called nodes and antinodes, respectively.

The effect of these vibrations is invisible until a medium – usually a liquid, or fine particles of a solid material such as sand or salt – is added to the plate. When the generator is set to one of the plate's natural frequencies, the water or sand will shift away from the busy antinodes and towards the quieter node regions. The resulting figures vary depending on the rate of oscillation as well as the shape and size of the Chladni plate, but all demonstrate unbelievable symmetry.

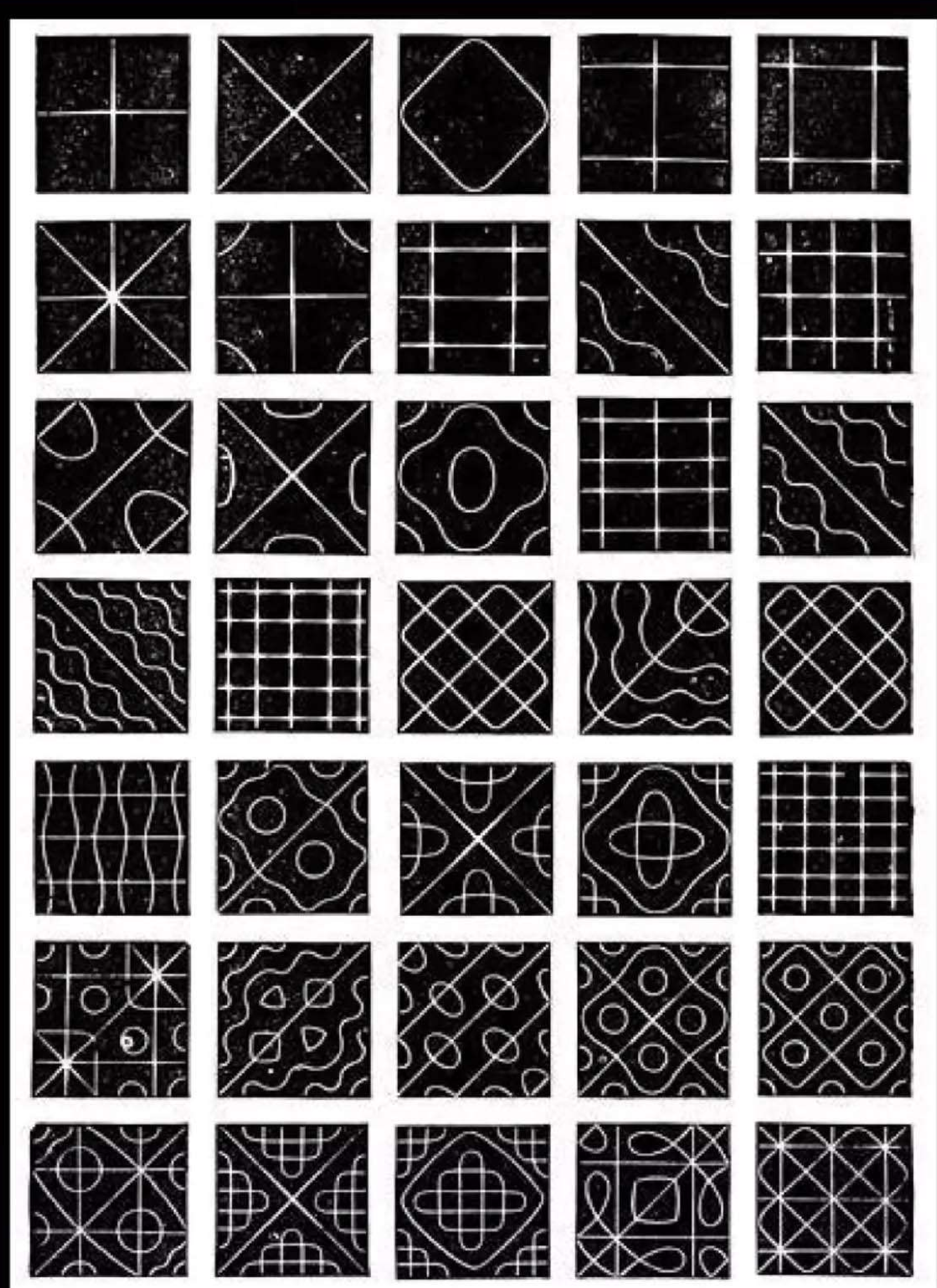
This method for visualising sound, as well as being a remarkable form of natural art, can be used across many fields of scientific research. One example is oceanography, where the cymatic patterns of dolphin sonar are being used to better understand how the marine mammals communicate.



Ernst Chladni

German-born physicist and musician Ernst Florens Friedrich Chladni investigated cymatics around the turn of the 19th century. By running a violin bow along the edge of a metal plate covered in fine sand, he was able to make the plate vibrate at its resonant frequency, producing intricate patterns in the grains. Chladni experimented with a variety of plate shapes and sizes, making extensive sketches of the different sand patterns (right), which were published in his book *Die Akustik* (*The Acoustic*) in 1802. From his studies, he was able to derive a formula known as Chladni's Law, which predicts the patterns that will form on circular plates.


Ernst Chladni was a research pioneer in the field of cymatics

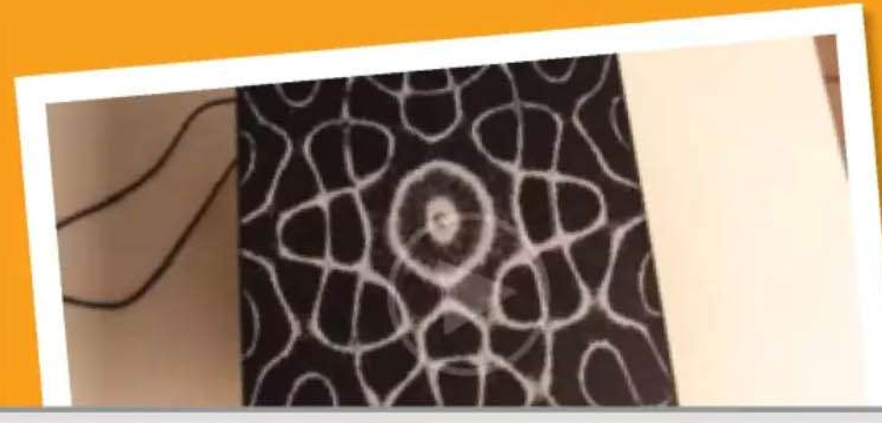


AMAZING VIDEO!

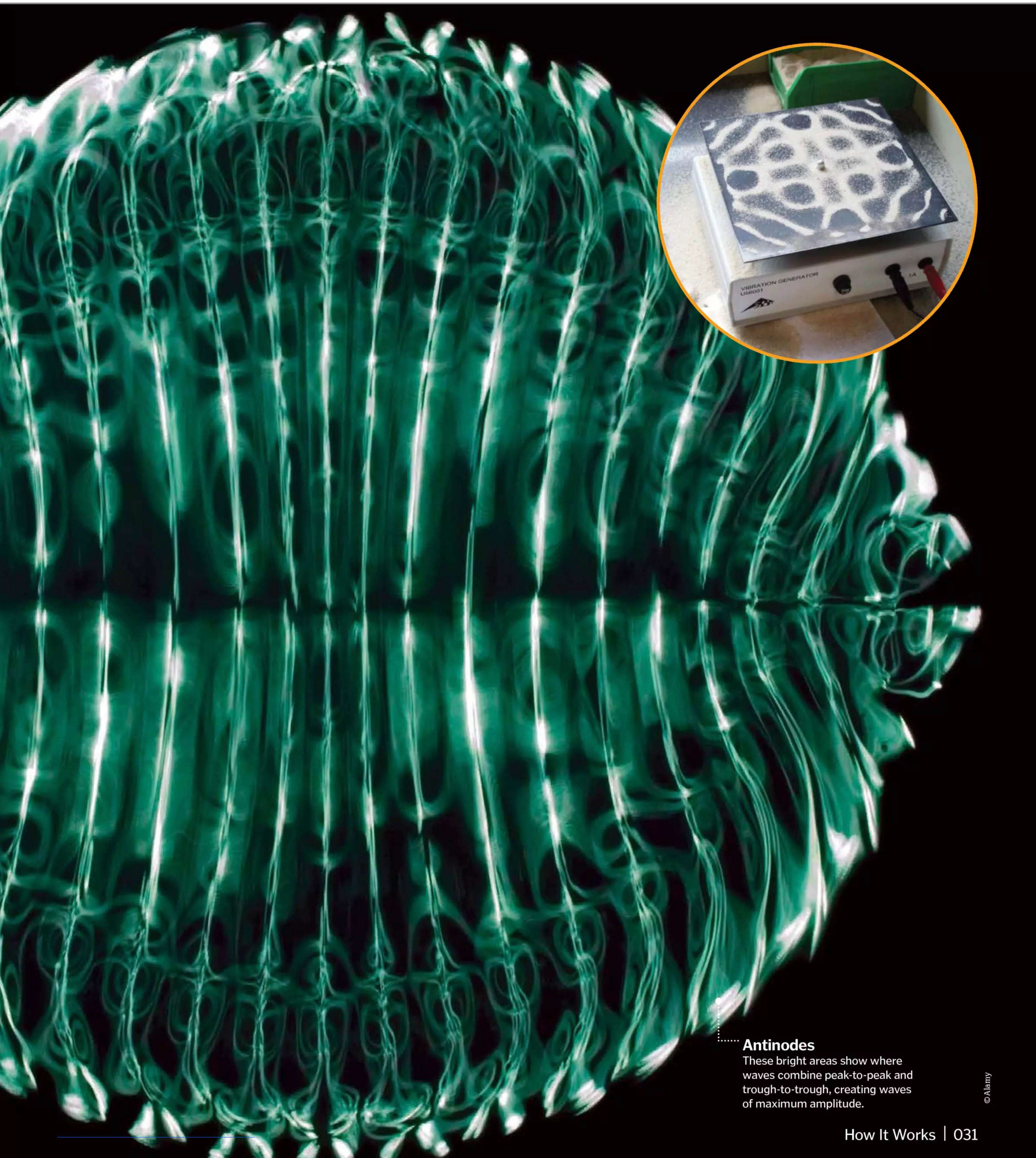
SCAN THE QR CODE FOR A QUICK LINK

Check out a Chladni plate experiment in action

www.howitworksdaily.com



DID YOU KNOW? *Napoleon was so impressed by Chladni's cymatics research he funded a French translation of Die Akustik*

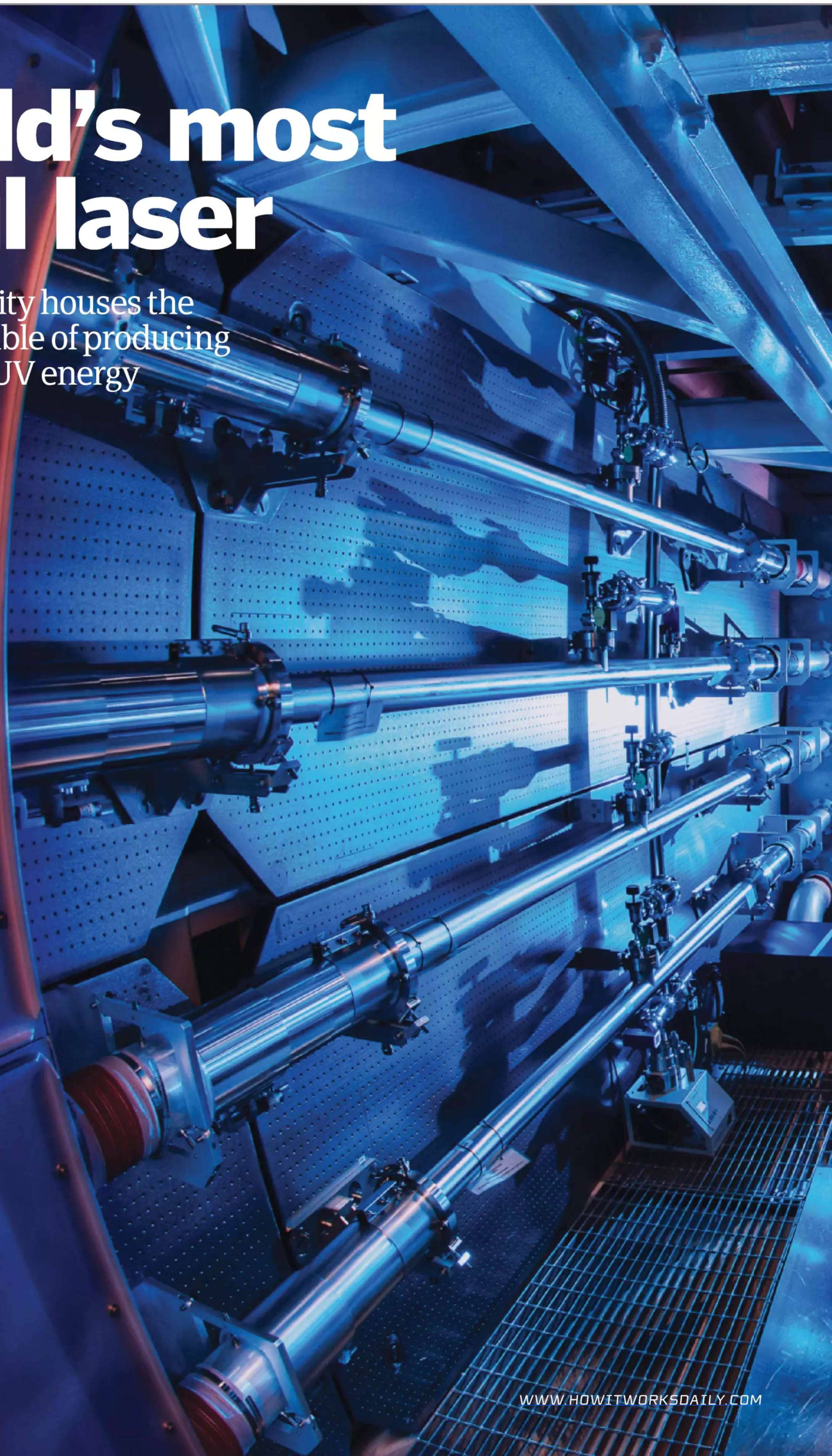


Antinodes
These bright areas show where waves combine peak-to-peak and trough-to-trough, creating waves of maximum amplitude.

"It contains the largest optical instrument ever built, 7,500 flash-lamps and 97 kilometres of mirrors"

The world's most powerful laser

The National Ignition Facility houses the planet's biggest laser, capable of producing around 2 million joules of UV energy



At least 60 times more powerful than its predecessors, the laser at the National Ignition Facility (NIF) in California is an impressive feat of engineering. It contains the largest optical instrument ever built, 7,500 flash-lamps, 97 kilometres (60 miles) of mirrors and fibre optics, and is roughly the size of three football pitches.

At the master oscillator of the NIF, a low-energy pulse of photons is generated using an optical fibre laser. To amplify the laser pulse it is broken down into 192 separate beams; these are then carried through fibre-optic cables to a series of amplifiers.

Powerful white flash-lamps are used to energise sheets of neodymium-impregnated phosphate glass, which energises electrons in the neodymium atoms. As the photons pass through the amplifier they cause the electrons to drop back to their 'ground state', and in the process more photons are released. The photons collide and vibrate together, creating a stream of photons all of the same wavelength and travelling in a single direction.

An optical switch in the amplifier works like a mirror and forces the photons to travel back and forth, bumping in to more electrons and producing more and more identical photons. This process boosts the power of each beam from a fraction of a joule to over 20,000 joules.

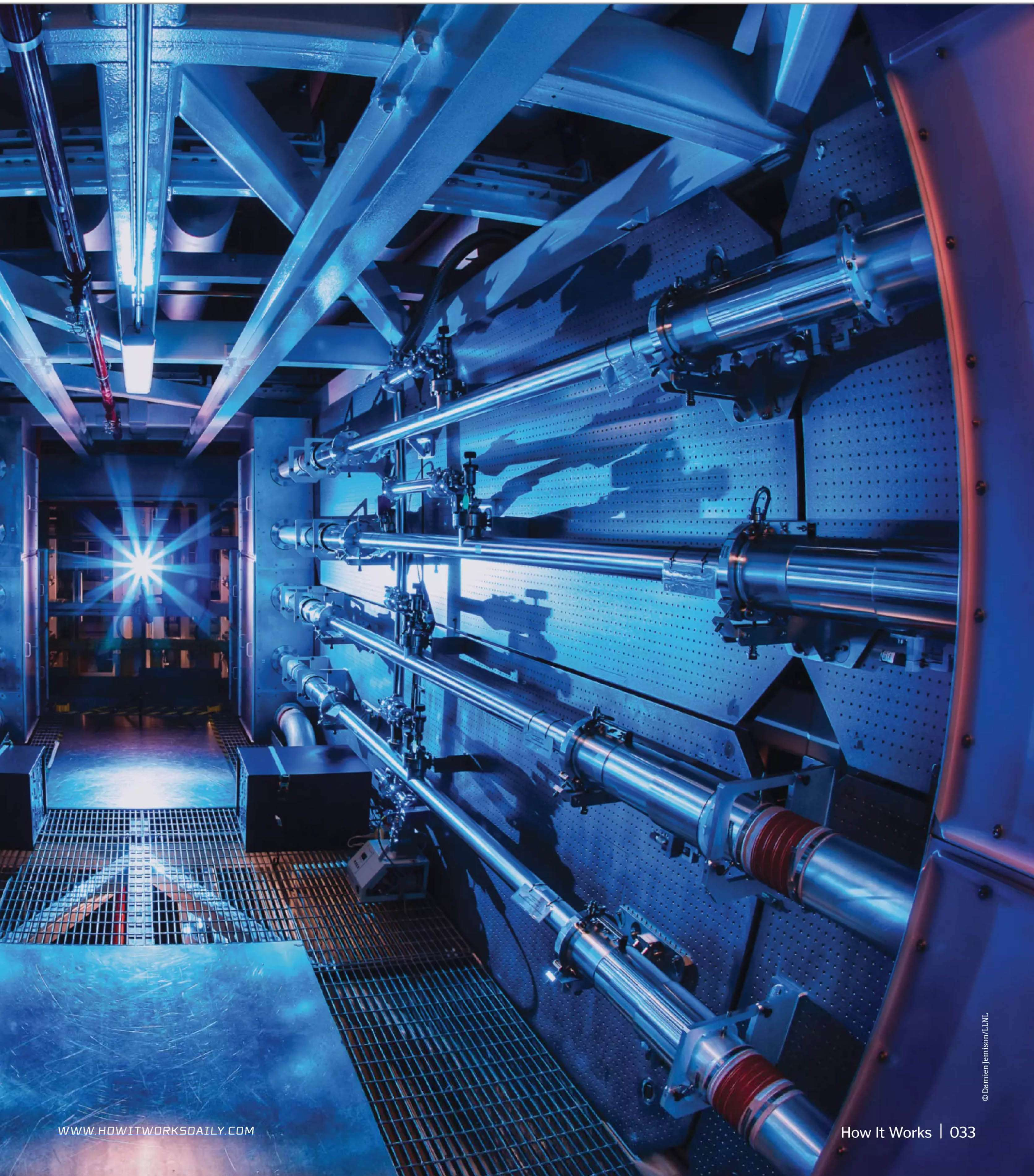
Once the beams have been amplified, two ten-storey mirrored 'switchyards' focus them into a spherical target chamber, pinpointing a target smaller than a pencil eraser. The combined power of all 192 beams heats the target to 100 million degrees Celsius (180 million degrees Fahrenheit) – more than six times hotter than the core of the Sun – and puts it under a force exceeding 100 billion atmospheres, all in less than a second.

THE STATS
NIF LASER

TIME **4.5 microseconds** DISTANCE TRAVELLED **1,500m** TARGET SIZE **5mm**

TARGET PRESSURE **100bn atmospheres** TARGET TEMPERATURE **100mn°C**

DID YOU KNOW? *When digging the foundations for NIF, a 16,000-year-old mammoth fossil was found; it was nicknamed Niffy*



© Damien Jemison/LLNL

Red

Red can't be seen underwater. Water absorbs longer wavelengths of light, so once you get beyond about ten metres (33 feet), red light is almost entirely filtered out. The colour provides great camouflage for certain sealife and divers sometimes notice their blood looks dark green if they cut themselves!

What about pink?

There's no pink in the spectrum of visible light. While the colours of the rainbow each correspond to a band of wavelengths of light, there is no 'pink' wavelength. What our brains interpret as pink is actually a mixture of red and blue light waves.

Light &

We take our multicoloured world for granted, but life would be much duller if it wasn't for a trick of the light

Orange

In nature, yellow and orange are often produced by the carotenoid pigment. As their name suggests, carotenoids are found in large quantities in carrots, but also egg yolks and autumn leaves. While it's not true that eating carrots will improve your vision, your body converts some carotenoids into vitamin A, which is a must for healthy eyes.

Yellow

Astronomers classify stars according to their colour, which matches their surface temperature. Our Sun is a yellow (or G-type) star, meaning that its surface temperature is around 5,500 degrees Celsius (10,000 degrees Fahrenheit). Stars remain in this class for around 10 billion years, so our Sun still has a good 4-5 billion years left.

Seeing red
1 Like a large number of animals, bulls are colour blind and can't see red. So it's a common misconception that a matador's red cloth is what gets a charging bull wound up.

Sticky light
2 Try ripping a piece of sticky tape off the roll in the dark. This separates positive and negative electrical charges – when they recombine, it creates a flash of blueish light.

Slow sparkle
3 Want to slow light down? It travels at its slowest inside a diamond. Even then, it still manages a fairly impressive 124,000 kilometres (77,000 miles) per second!

Whiter than white
4 Ever seen white clothes glow under a UV light? Laundry detergents contain optical brighteners, which emit blue light under UV to stop your whites from looking yellow.

How many colours?
5 By measuring our eyes' top performances, scientists have estimated that we can distinguish up to 10 million colours, though thankfully we don't have names for them all!

DID YOU KNOW? 90 per cent of deep-sea creatures have bioluminescent properties, emitting light using photophores

colour

Violet

Mauveine was the first synthetic dye, discovered by British chemist William Henry Perkin in 1856. Until then, the colour purple had been laborious and expensive to create from natural sources, with its basic ingredient being mucus from certain molluscs. Perkin's vivid violet dye made him very wealthy.

Blue

On a sunny day, the sky is a brilliant shade of blue. This colour comes from gas molecules in the atmosphere, which scatter mostly short blue wavelengths of light. The same effect can be observed by astronauts orbiting the Earth, who see a faint halo of blue around our planet.

Green

Why are plant leaves green? Plants use a pigment called chlorophyll to convert the Sun's light into energy. Chlorophyll absorbs red and blue light (possibly due to some ancient evolutionary advantage), and therefore reflects mostly light in the yellow and green parts of the spectrum; this is what gives plants their lush, verdant tones.

We all know what light is on a basic level, but its true nature has fascinated scientists from Ancient Greek times right up until the present day. Visible light (in other words, the light our eyes can perceive) is electromagnetic (EM) radiation – a type of energy which travels as a wave. Waves are disturbances which travel through space and, more specifically, EM waves are waves where the disturbances are changes in the electric and magnetic fields.

The light we see is just a tiny sliver of the EM spectrum, though, which encompasses the full range of wavelengths that electromagnetic waves can occupy. Other wavelengths of EM radiation include radio waves, ultraviolet, microwaves and X-rays, to name just a few.

But that's just half the story. While light's behaviour can often be understood by thinking of it as a wave, some of its properties only make sense when considering it to be a stream of particles – called photons. Confused yet? Physicists reconcile these conflicting observations by considering light to be both a particle *and* a wave – a concept which goes by the name of wave-particle duality. To avoid the headaches, it's easiest to think of light as a wave for most purposes.

Light on our planet comes mostly from the Sun. The Sun's blistering heat causes it to incandesce, or glow (just like the embers of a bonfire), emitting energy as light, which then travels some 149 million kilometres (93 million miles) to reach us. The same principle allows the filament in an old-fashioned incandescent light bulb to brighten up our homes.

Our eyes are sensitive to light of wavelengths between about 390 and 750 nanometres. Each 'colour' that we perceive corresponds to a band of wavelengths. Our brains interpret the shortest visible wavelengths as violet and the longest as red, thus giving rise to the terms ultraviolet (UV) and infrared (IR) for the invisible wavelengths lying just beyond the visible spectrum. While we tend to describe the rainbow as having seven colours, in reality it is a continuum of different shades.

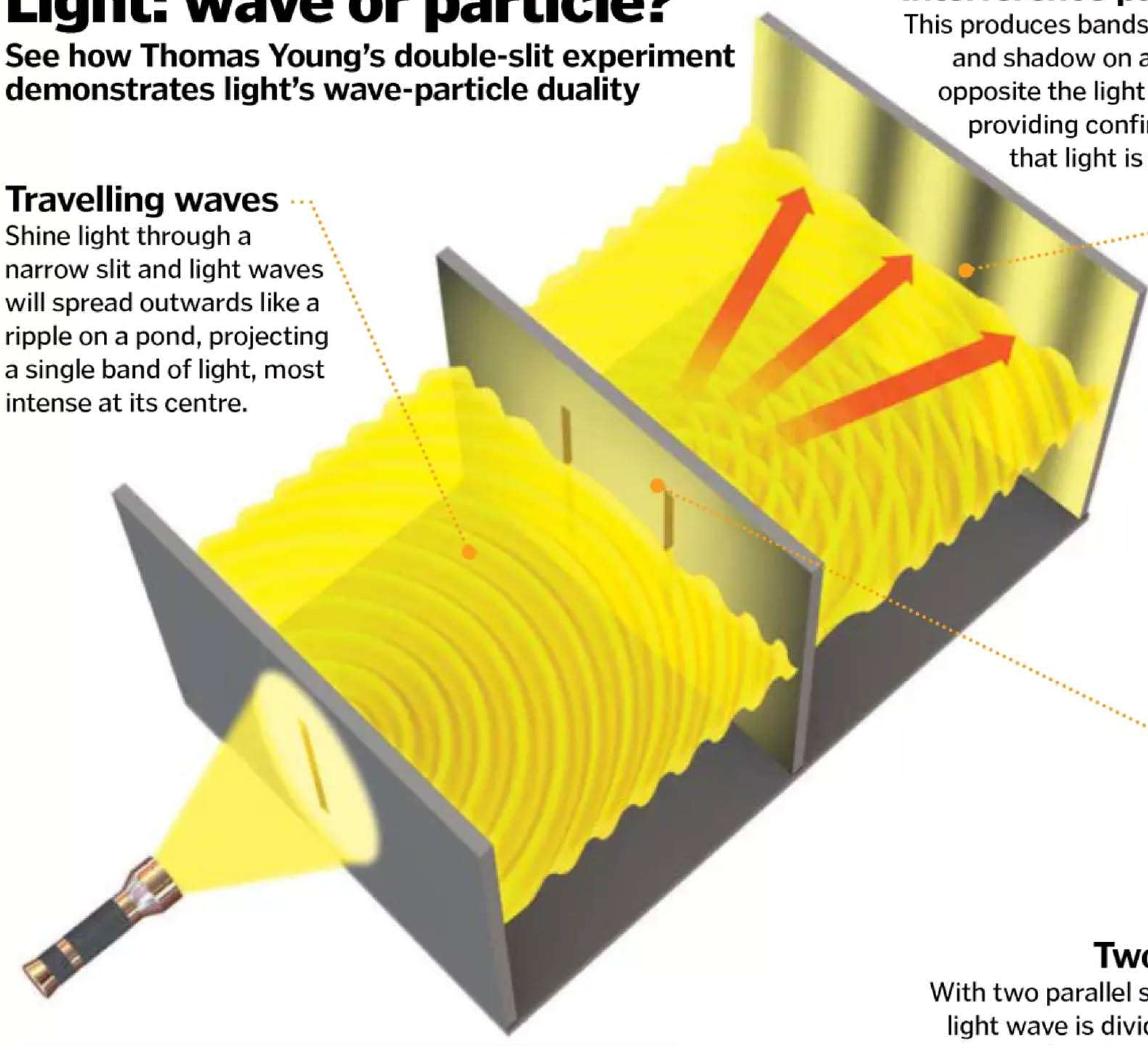
Though colours may seem very real to us, they are just our brains' way of interpreting this narrow band of EM radiation. Other animals see a completely different range of colours to us – and there are many variations in how humans see colour too.

Ever wondered why white isn't part of the rainbow? As Isaac Newton demonstrated when he shone the Sun's light through a prism, white ▶

"Chemical compounds called pigments are responsible for the majority of the colours we see in nature"

Light: wave or particle?

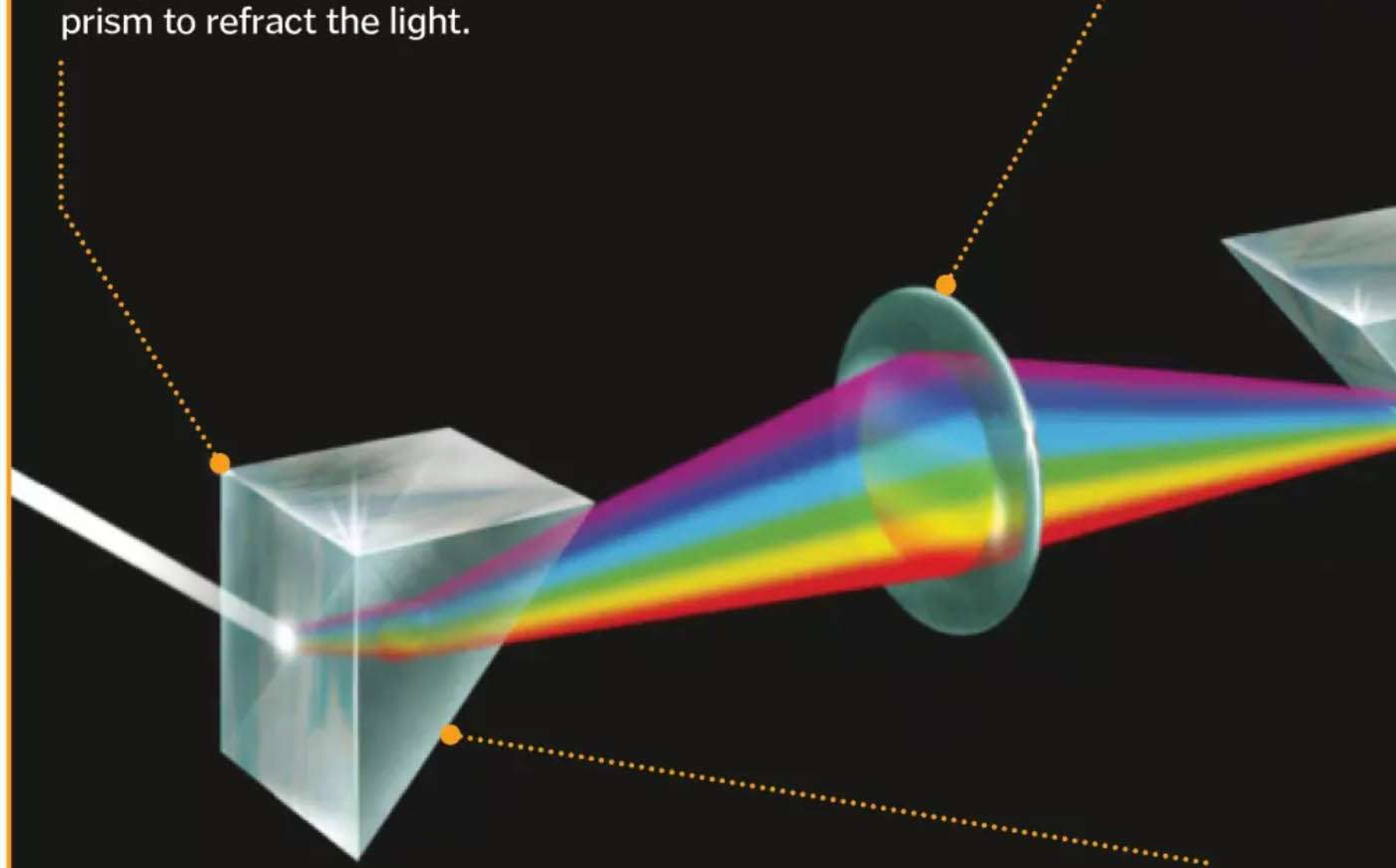
See how Thomas Young's double-slit experiment demonstrates light's wave-particle duality



In conclusion...
So what would happen if you fired photons one by one through the slits? In fact an identical interference pattern would slowly emerge. Crazy as it seems, this is evidence that an individual photon can interfere with itself. In other words, light can simultaneously act like a wave and a particle.

The colour spectrum

In 1665, Isaac Newton set out to prove that white light is made up of the full spectrum of colours...



light is actually made of the full spectrum of colours combined. When light waves hit an object they can be reflected, absorbed or transmitted. These interactions transform plain old white light to draw out the multitude of colours that we witness every day.

When you 'see' an object, what you are actually seeing is the light that it reflects. Reflection occurs when light hits a surface and the light waves bounce off it. Say you are looking at an apple. Light hits the apple and rebounds off it in all directions; this is called scattering. Some of this reflected light reaches your eyes, feeding your brain information on what the apple looks like.

If everything around us reflected the full spectrum of the Sun's white light perfectly, we'd see the world in shades of black and white. Instead, almost everything transforms white light in some way, creating everything from brilliant blues to murky browns.

Chemical compounds called pigments are responsible for the majority of the colours we see in nature. Pigments absorb certain wavelengths of light and so reflect only a portion of the visible spectrum – these reflected wavelengths are what we detect with our eyes and perceive as colour. A red apple, for example, absorbs green and blue wavelengths of light, reflecting mainly red light.

Many pigments are present in rocks and minerals, but living things like animals, plants and insects also make pigments of their own. Humans, for instance, produce a type of pigment called melanin, which is responsible for the full range of skin tones, as well as eye and hair colours, found throughout the human race. And while a few hundred years ago artists had to rely on natural pigments to create the colours on their paint palettes, synthetic pigments mean we can now adorn our houses, clothes and fingernails with just about any colour under the Sun.

When you mix different pigments in paint, you are actually combining the wavelengths they absorb. So if you mix cyan (blue) paint, which absorbs red and green light, with yellow paint, which absorbs blue light, you get a colour which absorbs red and blue light and reflects green light – in other words, green.

Pigments are just one of the mechanisms splashing colour into our world though. Another is refraction, which allows spectacular colours to be separated out of plain old white light. Light travels at different speeds depending on the medium it is passing through. Glass or water, for example, enforce much lower speed limits on light than air. When two different materials are in contact, light travelling through is forced to slam on the brakes. The change in speed as it passes from one medium to the other causes the beam of light to bend. This, in a nutshell, is refraction.

If you were to put a plastic straw into a glass of water and look at it from the side, it appears as though the straw is bent where the liquid meets the air. This is because light travels approximately 30 per cent more slowly through water than it does air. If you wear glasses or contact lenses you can thank refraction for helping you bring the world into focus.

What does this have to do with colours? Different wavelengths of light are refracted at slightly different angles, splitting white light into its component colours. Even minuscule

1. SHINY

Jewel beetle
With some 15,000 species found all over the world, beetles from the Buprestidae family display some dazzling metallic colours on their shell.

2. SHINIER

Morpho butterfly
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3. SHINIEST

Pollia condensata
This tiny African berry, aka the marble berry, packs an amazing punch, reflecting more light than any other living organism.

DID YOU KNOW? Isaac Newton once poked a needle around his eyeball to prove pressure and colour perception were related!

3. Focusing light
A convex lens focuses the spreading spectrum of colours, allowing the light to converge on the surface of the second prism.

5. Projection
The spectrum produced by a prism is tricky to see travelling through air, but can be observed much more easily if projected onto a white surface.

4. Recombining the rainbow
Passing through the second prism, the opposite effect occurs and the colours are recombined into white light by the process of refraction.

droplets of water can refract light, painting rainbows in the sky. Refraction is also what gives diamonds their multicoloured sparkle.

If you've ever looked at soap bubbles up close, you'll have seen the myriad colours on the surface. The technical term for this is iridescence, and it happens because light waves can interfere with one another when they cross paths. A bubble is, in essence, a very thin sheet of water sandwiched between two layers of soap molecules. When light hits the top surface of the bubble, some of it bounces off and the rest is transmitted down to the bottom surface, where it too is reflected, merging with the light reflected by the top surface.

Having travelled slightly farther, the light waves reflected from the bottom surface are now out of phase with those reflected from the top surface. When they meet, these two waves interfere with each other, amplifying certain wavelengths and dulling others. The result: vibrant colours that change depending on the angle from which you view them. The same effect can be seen on the underside of a CD or in some of nature's shiniest creatures.

The speed of light

Travelling through a vacuum, light zips along at just under 300,000 kilometres (just over 186,000 miles) per second. Almost all particles in our universe contend with the Higgs field, which interacts with them to give them mass. Photons – the particles which make up light – are the exception. They don't interact with the Higgs field and therefore possess no mass. This means that no energy is required to change their velocity and there is no limit to their speed. So why is 300,000 kilometres (186,000 miles) per second the cutoff? This is simply a fundamental property of our universe, a constant set in stone when the cosmos came into being.

How do we perceive colour?

The retinas of our eyes have three types of light receptors called cone cells. They respond to light in bands of wavelengths centred around red, green and blue. Each colour we see produces a different combination of responses from these cone cells, allowing our brains to tell millions of different colours apart.

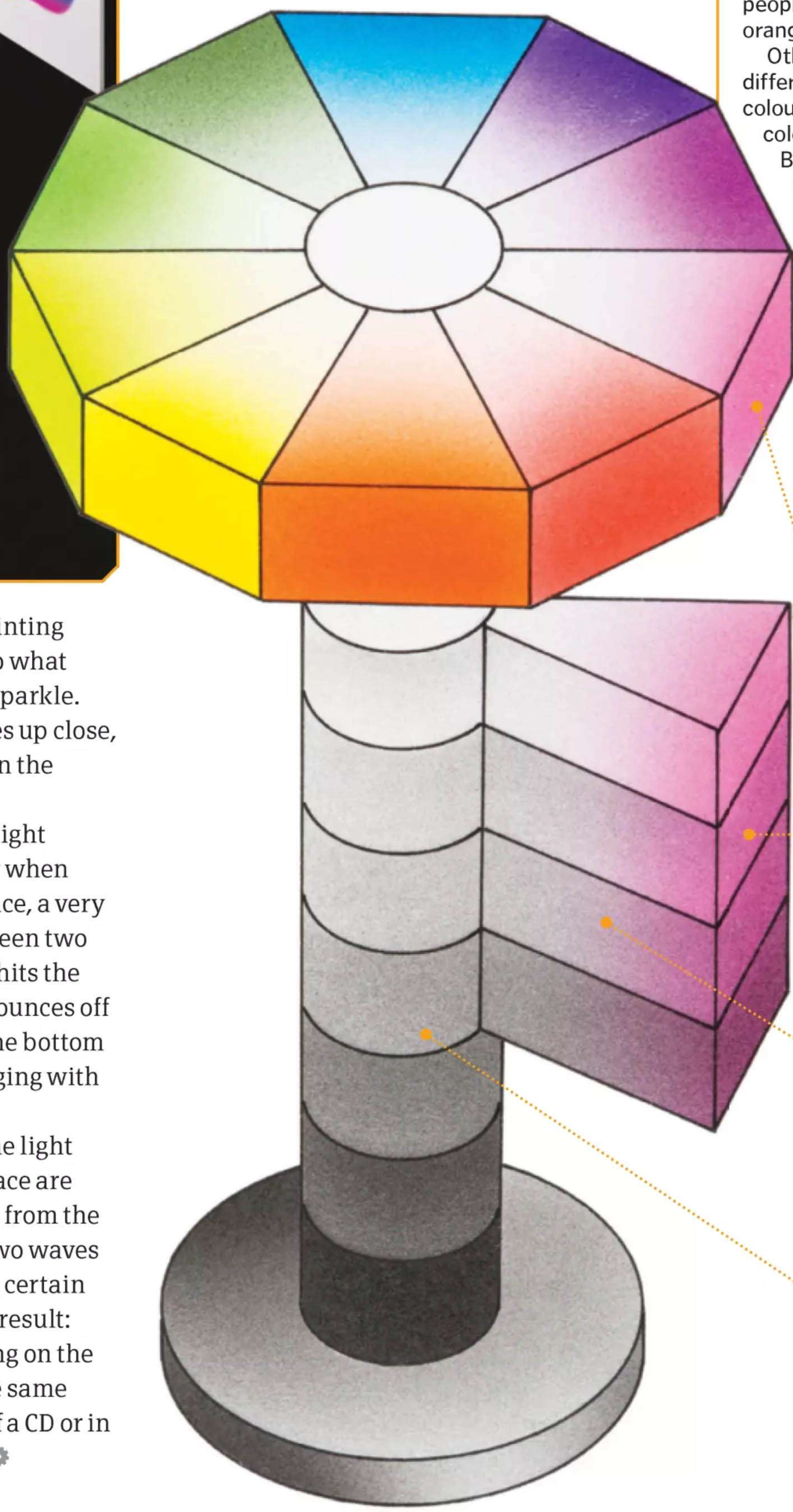
Some people, however, have faulty cone cells, causing colour blindness. In people with red-green colour blindness, the green cone cells are mutated, making colours shift towards the red end of the spectrum. As a result, these people have trouble distinguishing shades of red, orange, yellow and green.

Other people's brains are wired slightly differently, leading them to strongly associate colours with numbers or letters, or even see colours when they hear certain sounds. Play Beethoven's symphony to someone with sound-colour synaesthesia and the music will trigger visual fireworks.

Beyond these extreme variations in our perceptions of colour, it's quite possible that everybody experiences colour in subtly different ways.

Classifying colour

Albert Munsell's colour tree gives us an objective way of describing colours, splitting them into three dimensions: hue, value and chroma



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Naming a colour
Finally, a colour is named by listing its hue, value and chroma. This shade of pink would be called something like 5RP 4/10.

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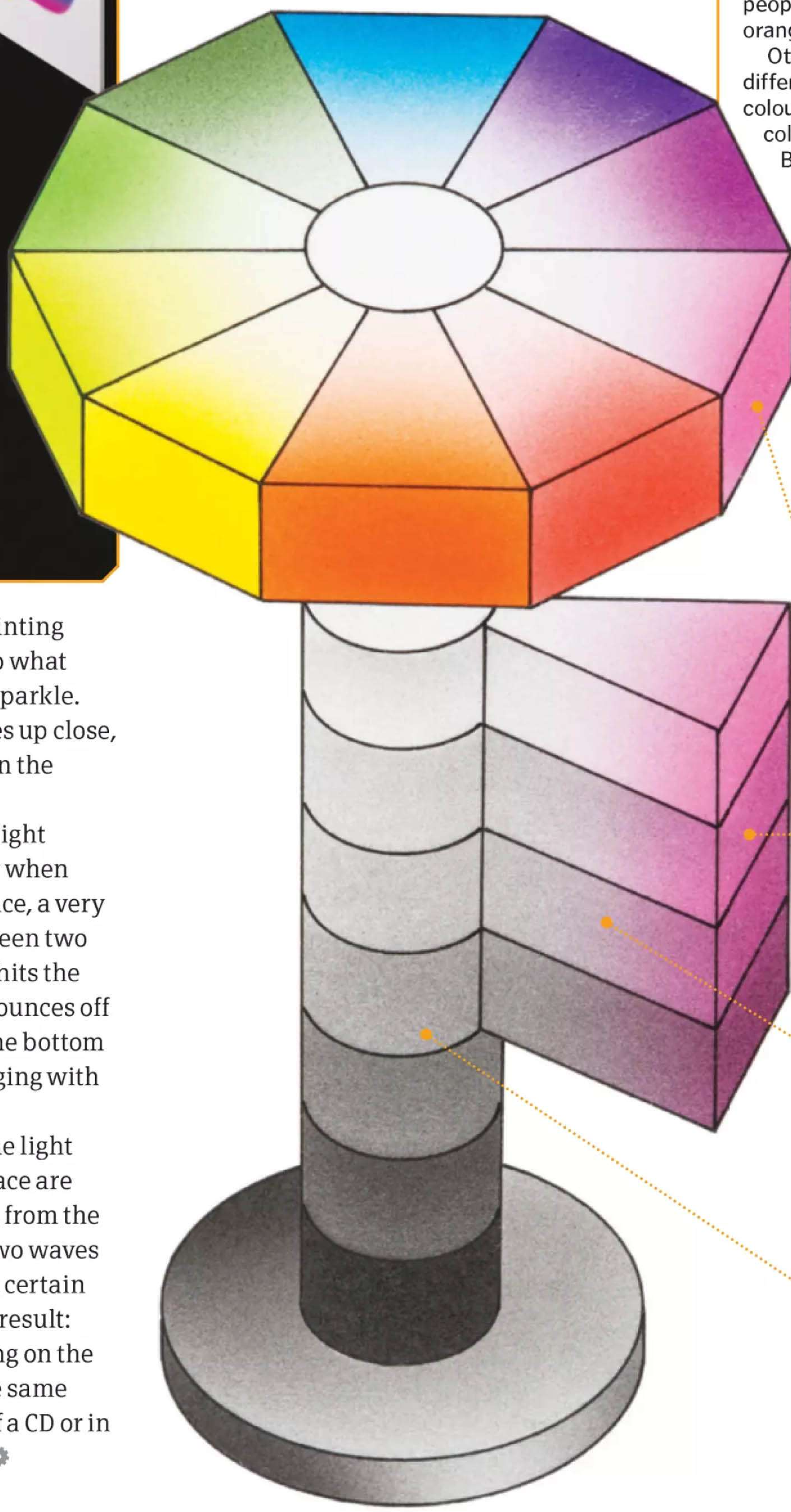

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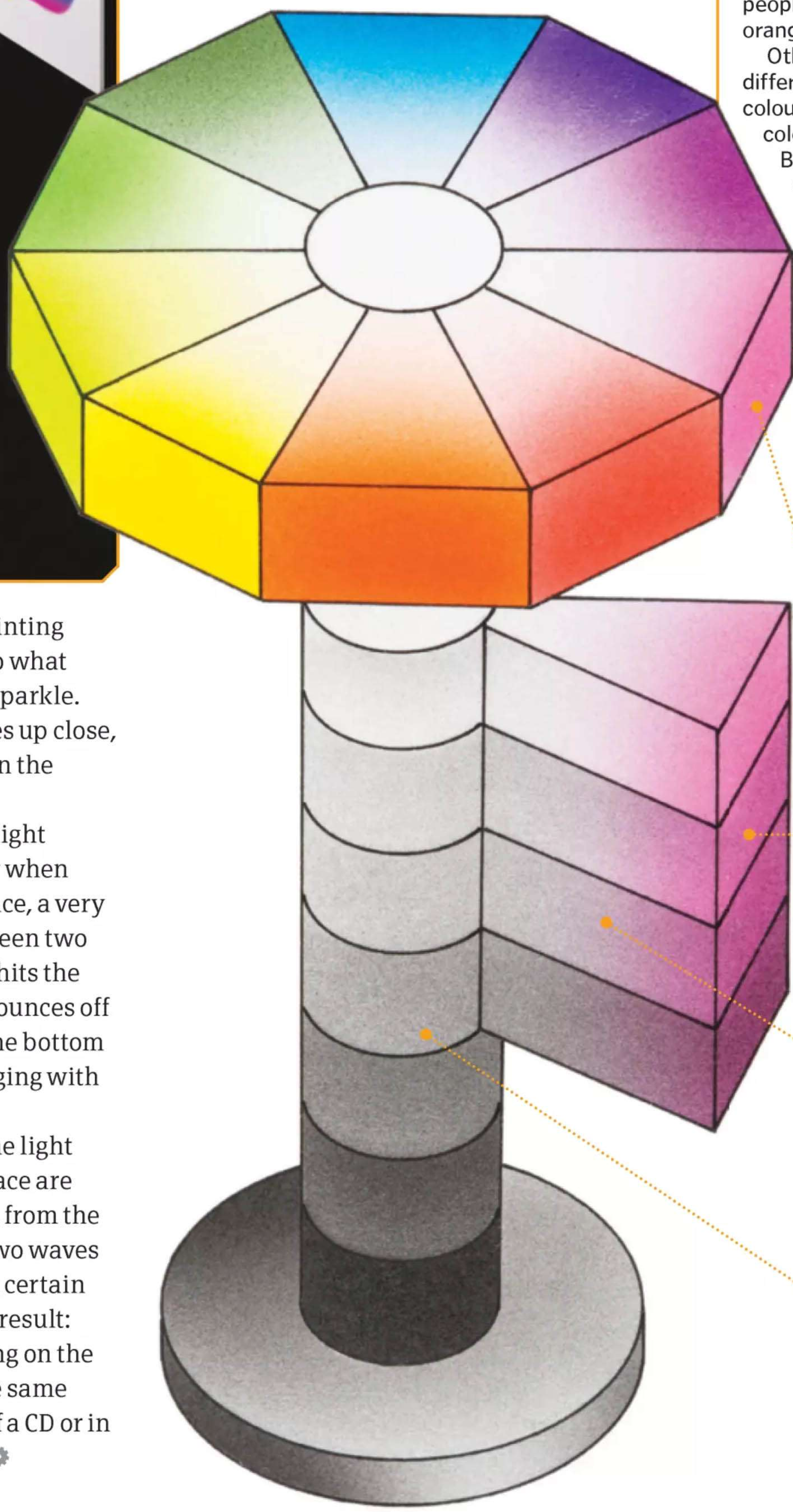

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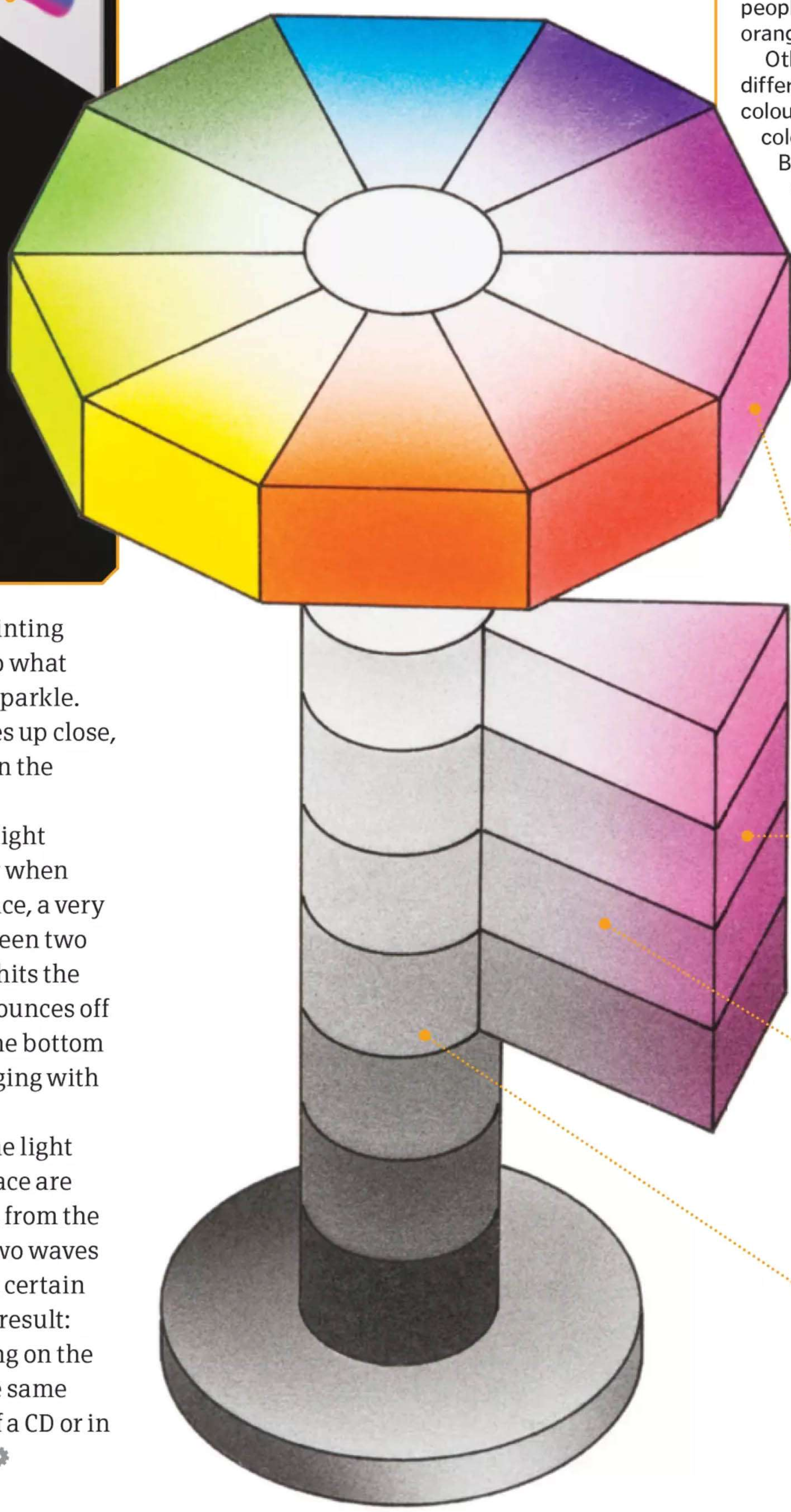

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